AMEREN MISSOURI LABADIE ENERGY CENTER

LABADIE SULFUR REDUCTION PROJECT

STANDARD OPERATING PROCEDURE

TELEDYNE ADVANCED POLLUTION INSTRUMENTATION MODEL T700 DYNAMIC DILUTION CALIBRATOR

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1. INTRODUCTION

Continuous gas analyzers used for ambient air quality monitoring applications must be periodically calibrated, checked for precision and accuracy and audited. This can be accomplished by use of a dilution calibrator equipped with precision MFCs and meters. Instructions for using a gas dilution calibrator for performing these checks on continuous gas analyzers are presented in Sections 5 and 6 of this SOP and in the analyzer-specific SOPs.

To maintain NIST-traceability of analyzer calibration checks, the MFCs in the dilution calibrator must be periodically calibrated using authoritative, NIST-traceable flow standards. This SOP presents information and procedures pertaining to this activity. Gas dilution calibrators used for performing analyzer calibration checks for air quality monitoring program applications typically contain two independently-settable mass-flow controlled flow meters; one for controlling the flow of gas delivered from an EPA Protocol-1 certified, pressurized, calibration gas standard (i.e., a cylinder), and one for controlling the flow of gas from a continuous pollutant-free, or "zero", air supply. The two flow streams (standard gas and dilution air) are combined in an internal mixing chamber downstream of the MFCs, where they are thoroughly mixed to produce a diluted test gas concentration. The diluted test gas is then directed to an output manifold equipped with one or more ports. Pneumatic tubing attached to one of the ports is used to direct the test gas to the analyzer sample inlet for analysis.

1.1 Diluent Gas (Zero Air)

Diluent Air is similar in chemical composition to the Earth's atmosphere but scrubbed of all components that might affect the calibrator's readings. Diluent Air should be dry (approximately -20ºC of Dew Point). Diluent Air should be supplied at a gas pressure of between 25 PSI and 35 PSI with a flow greater than the flow rate for the calibrator. For the standard unit this means greater than 10 SLPM. Zero air will be created using a Teledyne API Model 701 Zero Air Generator.

1.2 Calibration Gas

Calibration gas is a gas specifically mixed to match the chemical composition of the type of gas being measured at near full scale of the desired measurement range. Usually it is a single gas type mixed with N_2 although bottles containing multiple mixtures of compatible gases are also available (e.g. H_2S, O_2 and CO mixed with N_2). Calibration gas should be supplied at a pressure of between 25 PSI and 35 PSI with a flow greater than the flow rate for the calibrator. All calibration gases should be verified against standards of the National Institute for Standards and Technology (NIST). To ensure NIST traceability, cylinders of working gas that are certified to be traceable to NIST Standard Reference Materials (SRM) should be acquired. These are available from a variety of commercial sources.

1.3 Flow Standards For Calibrating Gas Dilution Calibrations

Flow standards utilized for calibrating gas dilution calibrators must be sufficiently accurate to ensure that the (calibrated) dilution calibrator flow rates are accurate within ± 2% of true.

Consequently, flow standards used to calibrate dilution calibrators should have an accuracy on the order of ±1%. This accuracy should be confirmed against a NIST-traceable primary or secondary flow standard, such as a bubble meter or bell prover. All test data demonstrating this accuracy (including the specific reference standard(s) and their NIST-traceability) should be reviewed and archived for future reference.

1.3.1 Types of Flow Standards

Assuming accuracy requirements stated above are met, there are a number of different kinds of flow standards which could be utilized for calibrating the flow controller(s) in a gas dilution calibrator. Three commonly-used, commercially available flow standards are as follows:

- Hastings HMB-1A Bubble Meters
- MKS "Transfer Standard Grade" Mass Flow Meters
- BIOS Dry Cal Flow Meters

The Hastings and BIOS flow standards measure volumetric flow rates, consequently, flow rate indications obtained using these instruments must be corrected to standard conditions for temperature (298^{o}K) and pressure (760 mmHg) (i.e., "STP"). The MKS (or equivalent) flow standard directly measures mass flow; and does not require correction of indicated flow rates to STP conditions, <u>provided the calibration data for these (mass flow meter) flow standards is referenced to STP conditions as defined above.</u>

Experience has shown that flow rate errors <u>may</u> occur when using the BIOS Dry-Cal flow standard in calibrating some brands of MFCs utilized in gas dilution calibrators. These errors can be engendered by interactions between the MFC being calibrated and the dynamic back-pressure characteristics inherent in the design of the BIOS flow standard (especially the BIOS "Low Flow" cell). Consequently, the accuracy of BIOS indicated flow rates obtained when calibrating MFCs with the BIOS should be empirically confirmed by inter-comparing the BIOS-indicated flow rate with an alternative flow standard. If discrepancies between the two flow standards exceed ± 2% at any flow setting, the BIOS should not be used in calibrating that particular model MFC.

1.3.2 Frequency of Calibrating Flow Standards

Following is the recommended minimum interval for calibrating (or "certifying") flow standards used for calibration of gas dilution calibrators:

- Hastings HBM-1A Bubble Meter: At time of manufacture and every ten years
- MKS "Transfer Standard Grade" Mass Flow Meter: every six months
- BIOS Dry Cal Flow Meters: once every 12 months

Additionally, flow standards should be re-calibrated whenever inter-comparison with an equivalent flow standard of known accuracy (the Hastings Bubble Meter is usually best for this purpose) exceeds ± 2%, or if their proper operation is believed to be suspect.

2. INSTRUMENT DESCRIPTION

The T700 Dynamic Dilution Calibrator generates calibration gas mixtures by mixing bottled source gases of known concentrations with a diluent gas (zero air). Using several Mass Flow Controllers (MFCs) the T700 calibrator creates exact ratios of diluent and source gas by controlling the relative rates of flow of the various gases, under conditions where the temperature and pressure of the gases being mixed is known (and therefore the density of the gases). The CPU calculates both the required source gas and diluent gas flow rates and controls the corresponding MFCs.

This dilution process is dynamic. The T700's CPU not only keeps track of the temperature and pressure of the various gases, but also receives data on actual flow rates of the various MFCs in real time so the flow rate control can be constantly adjusted to maintain a stable output concentration. The T700 calibrator's level of control is so precise that bottles of mixed gases can be used as source gas. Once the exact concentrations of all of the gases in the bottle are programmed into the T700, it will create an exact output concentration of any of the gases in the bottle.

2.1 Pneumatic Operation

The T700 calibrator pneumatic system consists of the precision dilution system and valve manifold consisting of four gas port valves and one diluent air valve. When bottles of source gas containing different, gases are connected to the four source-gas inlet-ports, these valves are used to select the gas type to be used by opening and closing off gas flow from the various bottles upstream of the MFCs. By closing all of the four source gas input valves so that only zero air is allowed into the calibrator, the entire pneumatic system can be purges with zero air without having to manipulate the MFCs.

2.2 Gas Flow Control

The precision of gas flow through the T700 Dynamic Dilution Calibrator is centrally critical to its ability to mix calibration gases accurately. This control is established in several ways. Diluent and source gas flow in the T700 calibrator is a directly and dynamically controlled by using highly accurate Mass Flow Controllers. These MFCs include internal sensors that determine the actual flow of gas though each and feedback control circuitry that uses this data to adjust the flow as required. The MFCs consist of a shunt, a sensor, a solenoid valve and the electronic circuitry required to operate them. The shunt divides the gas flow such that the flow through the sensor is a precise percentage of the flow through the valve. The flow through the sensor is always laminar.

The MFCs internal sensor operates on a unique thermal-electric principle. A metallic capillary tube is heated uniformly by a resistance winding attached to the midpoint of the capillary. Thermocouples are welded at equal distances from the midpoint of the tube. At zero air flow the temperature of both thermocouples will be the same. When flow occurs through the tubing, heat is transferred from the tube to the gas on the inlet side and from the gas back to the tube on the outlet side creating an asymmetrical temperature distribution. The thermocouples sense this decrease and increase of temperature in the capillary tube and produce a mVDC output signal proportional to that change that is proportional to the rate of flow through the MFCs valve.

The electronic circuitry reads the signal output by the thermal flow sensor measured through a capillary tube. This signal is amplified so that it is varies between 0.00 VDC and 5.00 VDC. A separate 0 to 5 VDC command voltage is also generated that is proportional to the target flow rate requested by the T700’s CPU. The 0-5VDC command signal is electronically subtracted from the 0-5VDC flow signal. The amount and direction of the movement is dependent upon the value and the sign of the differential signal.

The MFCs valve is an automatic metering solenoid type; its height off the seat is controlled by the voltage in its coil. The controller’s circuitry amplifies and the differential signal obtained by comparing the control voltage to the flow sensor output and uses it to drive the solenoid valve. The entire control loop is set up so that as solenoid valve opens and closes to vary the flow of gas through the shunt, valve and sensor in an attempt to minimize the differential between the control voltage for the target flow rate and the flow sensor output voltage generated by the actual flow rate of gas through the controller.

This process is heavily dependent on the capacity of the gas to heat and cool. Since the heat capacity of many gases is relatively constant over wide ranges of temperature and pressure, the flow meter is calibrated directly in molar mass units for known gases (see Section 3.3.7.3 of the TAPI 700 Operation Manual). Changes in gas composition usually only require application of a simple multiplier to the air calibration to account for the difference in heat capacity and thus the flow meter is capable of measuring a wide variety of gases.

2.3 Internal Gas Pressure Sensors

The T700 includes a single pressure regulator. Depending upon how many and which options are installed in the T700 calibrator, there are between two and four pressure sensors installed as well. In the basic unit a printed circuit, assembly located near the front of the calibrator near the MFCs includes sensors that measure the pressure of the diluent gas and the source gas currently selected to flow into the calibrator. The calibrator monitors these sensors. Should the pressure of one of them fall below 15 PSIG or rise above 36 PSIG a warning is issued.

3. INSTALLATION AND SET-UP

3.1 Unpacking

Unpack the instrument according to the guidelines presented in Chapter 3 of the Operation Manual. Verify that there is no apparent external shipping damage. If damage has occurred, please advise the shipper first, then Teledyne API. Included with the analyzer is a printed record of the final performance characterization performed on the instrument at the factory. It is titled *Final Test and Validation Data Sheet* (*P/N 05731*). This record is an important quality assurance and calibration record for this instrument. It should be placed in the quality records file for this instrument.

With no power to the unit, carefully remove the top cover of the analyzer and check for internal shipping damage by carrying out the following steps:

a. Remove the locking screw located in the top, center of the front panel;
b. Remove the two flat head, Phillips screws on the sides of the instrument;
c. Slide the cover backwards until it clears the analyzer's front bezel, and;
d. Lift the cover straight up.
e. Inspect the interior of the instrument to ensure that all circuit boards and other components are in good shape and properly seated.
f. Check the connectors of the various internal wiring harnesses and pneumatic hoses to ensure that they are firmly and properly seated.
g. Verify that all of the optional hardware ordered with the unit has been installed. These are listed on the paperwork accompanying the analyzer.

3.2 Assembly And System Integration

3.2.1 Assembly and Installation

Assemble the instrument according to the guidelines presented in Chapter 3 of the TAPI T700 Operation Manual. The monitoring station design calls for rack-mounting of the analyzer. Install the male parts of the supplied slide rails on the sides of the analyzer and the corresponding female parts of the rail slides in the instrument rack. Ensure there will be adequate vertical clearance with respect to other rack-mounted instrumentation and that the location of the analyzer in the rack will permit easy access for service and maintenance. Mate the rail slide sections and install the analyzer in the rack. Ensure the analyzer slides smoothly on the rails into the rack and back out in the fully extended position. Section 3.1 of the TAPI T700 Operation Manual lists the minimum required ventilation clearance for the instrument.

3.2.2 Pneumatic Interconnections

(a) All materials employed for calibration gas to the dilution calibrator shall be comprised type 316 stainless steel. The connections to the T700 dilution calibrator for calibration gas delivery will be made using 1/8" O.D. type 316 stainless steel tubing and stainless steel fittings. Leak-tight compression fittings (e.g., Swagelok) are typically used for connecting tubing to port fittings. Calibration gas delivery lines should not exceed 10 feet in total length. Connect the calibration gas delivery line from the bottled gas mixture to the “CYL 1” port on the rear bulkhead of the dilution calibrator. If a second calibration gas bottle is used, connect that calibration gas delivery line from the second bottled gas to the “CYL 2” port on the rear bulkhead of the dilution calibrator.

(b) Consult the monitoring station system pneumatic interconnection diagram. The analyzers incorporate an internal solenoid valve (for switching of the gas stream supplied to the analyzer from sample air to calibration gas in support of automatic calibration checks). Make calibration gas delivery connections from the dilution calibrator’s “CAL OUT’ port to the analyzers by connecting a length of 1/4" O.D. Teflon tubing to the “SPAN GAS” inlet port on the rear bulkhead of the analyzer. **Ensure the lines that deliver the calibration gas to the analyzer incorporate an atmospheric bypass dump (i.e., a “tee” union fitting with an unobstructed vent)** as indicated in the site pneumatic interconnection diagram. This will ensure that calibration gases are delivered to the analyzer at (or near) atmospheric pressure. This unobstructed vent should be connected to an unused port on the site exhaust manifold, where the exhaust will be expelled to the outside atmosphere.

3.2.3 Electrical Interconnections

Use standard single- or multi-pair, stranded (18~20 AWG), shielded, low-voltage signal cable with PVC or similar jacketing for all low-voltage electrical connections. Use U.L-approved and/or National Electric Code (NEC)-approved materials for making all higher (line) voltage connections. Attach the power cord to the dilution calibrator and plug it into a power outlet capable of carrying at least 10 Amps of current at your AC voltage and that it is equipped with a functioning earth ground. Ground terminals on all line-voltage power connections shall be used. Terminations on low-voltage wiring may be made using bare wire, solderless or soldered techniques and hardware, as indicated. Care should be exercised to ensure reliable connections. Exposed bare wire lengths at termination points should be kept as short as possible to avoid short-circuits. All wiring runs should be neatly organized, dressed, tagged for identification, and routed for ready access and serviceability.

(a) Connect the on-site data recording device to the Ethernet and Control Input ports located at the rear of the instrument according the connections specified in the site electrical interconnection diagram. Note the polarity and the specified full scale input voltage range for these devices and be sure they match the corresponding full scale output voltage range from the instrument.

(b) The site operation plan calls for automatic zero/span checks. Make the appropriate electrical connections from the on-site datalogger control output terminals to the control input(s) that route delivery of the calibration gases used for these checks (these connections are specified in the site electrical interconnection diagram). Be sure to observe correct wiring polarity.

(c) Connect the supplied line voltage power cord to a convenient electrical outlet supplying 115VAC at 60Hz.

3.2.4 Configure Dilution Calibrator Operating Parameters

After the electrical and pneumatic connections are made, perform an initial functional check. Turn on the instrument. The pump and exhaust fan should start immediately. The display will show a momentary splash screen of the Teledyne API logo and other information during the initialization process while the CPU loads the operating system, the firmware and the configuration data.

Once the CPU has completed this activity, it will begin loading the calibrator firmware and configuration data. During this process, model and software revision information appear briefly in the Param field of the calibrator's front panel display before the firmware is fully booted. The calibrator should automatically switch to **STANDBY** mode after completing the brief boot-up sequence.

The T700 dynamic dilution calibrator requires a minimum of 30 minutes for all of its internal components to reach a stable operating temperature. During the warm-up period, the front panel display may show messages in the Parameters field. Because internal temperatures and other conditions may be outside be specified limits during the calibrator's warm-up period, the software will suppress most warning conditions for 30 minutes after power up. If warning messages persist after the 30 minutes warm up period is over, investigate their cause using the troubleshooting guidelines in Section 11 of the TAPI 700 Operation Manual.

After the calibrator's components have warmed up for at least 30 minutes, verify that the software properly supports any hardware options that are installed. Check to ensure that the calibrator is functioning within allowable operating parameters. Appendix C of the TAPI 700 Operation Manual includes a list of test functions viewable from the calibrator's front panel as well as their expected values. These functions are also useful tools for diagnosing problems with the calibrator

The Final Test and Validation Data Sheet (P/N 05731) shipped with the instrument lists the factory-set values before the instrument left the factory. To view the current values of these parameters toggle the **<TST TST>** control buttons on the analyzer's front panel to scroll through the list of parameters that the instrument is configured for. Remember until the unit has completed its warm up these parameters may not have stabilized.

The user can alternatively interrogate, configure and download information from the analyzer using the analyzer's Ethernet port connected to a local or remote IBM-compatible personal computer (PC) using a Windows^{tm} operating system and running the TAPI communications software. Connections can be made using supplied cables. The on-site data logger has been pre-loaded with the TAPI communications software. The cellular modem and service supplied to the site supports remote communications via the Ethernet port. The user should refer to Appendix B in the TAPI T700 Operation Manual and the TAPI Communications Software Manual for detailed information on effecting and utilizing this communication capability.

3.2.4.1 Setting Up The Calibration Gas Inlet Ports

The T700 Dynamic Dilution Calibrator generates calibration gases of various concentrations by precisely mixing component gases of known concentrations with diluent (zero air). It is necessary to program the concentrations of the component gases being used into theT700's memory. The T700 calibrator is programmed with default gas types corresponding to the most commonly used component gases, including SO_2, H_2S and CO. The T700 calibrator can accept up to four different user defined gases. This allows the use of:

- Less common component gases not included in the T700's default list;
- More than one bottle of the same gas but at different concentrations. In this case, different user-defined names are created for the different bottles of gas.

To define a USER GAS, please refer to Section 3.3.7.2 of the TAPI 700 Operation Manual. Follow the following steps to set up the calibration gas inlet ports for this monitoring program:

(a) Make sure that the T700 is in STANDBY mode.

(b) On the front panel display, press the "SETUP" button to enter the PRIMARY SETUP MENU. In the lower left corner of the Primary Setup Menu display screen, press the "GAS" key to enter the Source Gas Configuration. In the Source Gas Configuration screen, press the "CYL" key to enter the Cylinder Gas Configuration. Press the "PRT1" to enter the Cylinder Gas Configuration for calibration gas port 1. The display should read "NONE". Press the "EDIT" key to enter the desired gas type. The "NONE" key will become highlighted. Continue pressing this key until the desired gas type is reached. The label for this button will change dynamically as the available gas list is cycled. Toggle the Concentration buttons to change the target concentration, the units of measure button to change the units of measure to ppb, ppm, etc. Press ENTR to accept the new gas name. If a cylinder containing multiple gases is to be programmed, press the "ADD" key until the desired gas type is reached and follow the procedure for entering the information for that gas including the target concentration for the second gas, the units of measure for the second gas repeat until all of the gases and concentrations in the canister are entered. Press the ENTR key to accept the new GAS NAME.

(c) Repeat Step b. above for each of the T700 calibrator's four gas inlet ports. If no gas is present on a particular port, leave it set for the default setting of NONE.

3.2.4.2 Setting the T700's Total Gas Flow Rate

The default total gas flow rate for the T700 Dynamic Dilution Calibrator is 2 LPM. The calibrator uses this flow rate, along with the concentrations programmed into the calibrator for the component gas cylinders during set up, to compute individual flow rates for both diluent gas and calibration source gases in order to produce calibration mixtures that match the desired output concentrations.

This Total Flow rate may be changed to fit the users' application. Once the flow is changed, then the new flow value becomes the total flow for all the gas concentration generated and computes again the individual flow rates of the component gases and diluent accordingly.

The minimum total flow should equal 150% of the flow requirements of all of the instruments to which the T700 will be supplying calibration gas. Example: If the T700 is expected to supply calibration gas mixtures simultaneously to a system composed of three analyzers each requiring 0.7 LPM, the proper Total Flow output should be set at:

$$(0.7 + 0.7 + 0.7) \times 1.5 = 3.150 \text{ LPM.}$$

To set the TOTAL FLOW of the T700 dilution calibrator, make sure that the T700 is in the STANDBY mode. Press the SETUP key to enter the Primary Setup Menu and press the MORE key to enter the Secondary Setup Menu. Press the FLOW key to enter the FLOW MENU. Press the TARG button and the TARGET FLOW screen will appear. Toggle the flow buttons to change the target TOTAL FLOW rate. Press the ENTR button to accept the new target total flow.

It is anticipated that the total flow necessary to achieve the proper calibration gas dilution and provide sufficient flow to the analyzers for this program will be approximately 5 LPM. The calibrator's TOTAL FLOW should be set to this flow rate.

3.2.4.3 Setting the T700's Automatic Calibration Sequences

The T700 calibrator can be set up to perform automatic calibration sequences of multiple steps. These sequences can perform all of the calibration mixture operations available for manual operation and can be initiated by one of the following methods:

- front panel touch screen buttons;
- internal timer;
- external digital control inputs;

- RS-232 interface;
- Ethernet interface; and
- sub-processes in another sequence.

The monitoring program calls for automatic calibrations initiated by the data logger. This can be accomplished using programmed sequences in the T700 that can be initiated at the correct time by the data logger. The following sequences should be programmed into the T700 to effect the automatic calibrations initiated by the data logger. Follow the procedure in Section 6.5.2 of the TAPI T700 Operation Manual to assign the sequence name and insert the appropriate instruction steps into the calibration sequence.

Sequence 1: Daily SO_2 Zero Span Level 1 Autocal

NAME: Sequence 1

STEPS to be inserted:

1. **MANUAL** generation of SO_2 span concentration*
2. **DURATION** of 15 minutes
3. **MANUAL** generation of zero concentration*
4. **DURATION** of 15 minutes
5. **PURGE** calibrator
6. **DURATION** of 2 minutes
7. **STANDBY** mode entered

Sequence 2: Weekly SO_2 Precision Zero Span Check

NAME: Sequence 2

STEPS to be inserted:

1. **MANUAL** generation of SO_2 span concentration*
2. **DURATION** of 15 minutes
3. **MANUAL** generation of SO_2 precision concentration*
4. **DURATION** of 15 minutes
5. **MANUAL** generation of zero concentration*
6. **DURATION** of 15 minutes
7. **PURGE** calibrator
8. **DURATION** of 2 minutes
9. **STANDBY** mode entered

*Refer to the current Form 4-1: Dilution Set Points and Flow Rates for each site for applicable gas and dilution set points and flow rates that should be programed in the calibrator.

4. MASS FLOW CONTROLLER (MFC) CALIBRATION

These instructions provide detailed information for operation, calibration and maintenance of gas dilution calibrators which utilize mass flow controllers (MFCs) for the regulation of gas flow and associated zero air supplies. It is intended to be used in conjunction with the manufacturer's instrument manuals.

Applications for the gas calibration system (dilution calibrator, zero air supply, and compressed calibration gas standards in cylinders) include: primary calibrations, precision checks, Level-1 Zero/Span checks and performance audits of continuous gas monitors used in air quality monitoring programs.

IMPORTANT: After the MFCs have been calibrated, the dilution calibrator set points and flow rates spreadsheet must be updated along with any programmed sequences in the calibrator and the data logger. Refer to Section 4.4 for the procedure to update the gas flow rates in the calibrator's programmed sequences and the corresponding gas concentrations in the calibrations sequences of the data logger.

4.1 <u>Introduction</u>

Continuous gas analyzers used for ambient air quality monitoring applications must be periodically calibrated, checked for precision and accuracy and audited. This can be accomplished by use of a dilution calibrator equipped with precision MFCs. Instructions for using a gas dilution calibrator for performing these checks on continuous gas analyzers are presented in Sections 5 and 6 of this SOP and in the analyzer-specific SOPs.

To maintain NIST-traceability of analyzer calibration checks, the MFCs in the dilution calibrator must be periodically calibrated using authoritative, NIST-traceable flow standards. This SOP presents information and procedures pertaining to this activity. Gas dilution calibrators used for performing analyzer calibration checks for air quality monitoring program applications typically contain two independently-settable mass-flow controlled flow controllers; one for controlling the flow of gas delivered from an EPA Protocol-1 certified, pressurized, calibration gas standard (i.e., a cylinder), and one for controlling the flow of gas from a continuous pollutant-free, or "zero", air supply. The two flow streams (standard gas and dilution air) are combined in an internal mixing chamber downstream of the MFCs, where they are thoroughly mixed to produce a diluted test gas concentration. The diluted test gas is then directed to an output manifold equipped with one or more ports. Pneumatic tubing attached to one of the ports is used to direct the test gas to the analyzer sample inlet for analysis.

4.1.2 Flow Standards for Calibrating Gas Dilution Calibrations

Flow standards utilized for calibrating gas dilution calibrators must be sufficiently accurate to ensure that the (calibrated) dilution calibrator flow rates are accurate within ± 2% of true. Consequently, flow standards used to calibrate dilution calibrators should have accuracy on the order of ±1%. This accuracy should be confirmed against a NIST-traceable primary or secondary flow standard, such as a bubble meter or bell prover. All test data demonstrating this accuracy (including the specific reference standard(s) and their NIST-traceability) should be reviewed and archived for future reference.

4.1.2.1 Types of Flow Standards

Assuming accuracy requirements stated above are met, there are a number of different kinds of flow standards which could be utilized for calibrating the flow controller(s) in a gas dilution calibrator. Four commercially available flow standards are as follows:

- Hastings HMB-1A Bubble Meter
- BIOS DC-2M Dry Cal Flow Meter
- MKS Type 0358c "Transfer Standard Grade" Mass Flow Meters
- Teledyne-Hastings Model HFM-D-300 "Transfer Standard Grade" Mass Flow Meter

The Hastings HB-1A Bubble Meters measure flow rates *volumetrically*, consequently, flow rate indications obtained using this instrument must be corrected to US EPA standard reference conditions ("STP") for temperature (298^{o}K) and pressure (760 mmHg). Thus, a certified thermometer having an accuracy of ±0.1 ^{o}C and barometric pressure standard having an accuracy of ±0.23 mmHg (±0.3mb) must be included in the calibration apparatus when using the Hastings Bubble Meter to calibrate MFCs.

The BIOS DC-2M Dry Cal flow meter simultaneously provides both volumetric and equivalent mass flow rates (i.e., flow rates referenced to STP). "Transfer Standard Grade" mass flow meters (MKS or equivalent) directly measure mass flow rates (i.e., flow rates referenced to SRC); consequently, the BIOS and mass flow meter types of flow standards do not require correction of indicated flow rates to STP conditions, <u>provided the calibration data for these (mass flow meter) flow standards is referenced to STP conditions as defined above.</u>

Experience has shown that flow rate errors <u>may</u> occur when using the BIOS Dry-Cal flow standard in calibrating some brands of MFCs utilized in gas dilution calibrators. These errors can be engendered by interactions between the MFC being calibrated and the dynamic back-pressure characteristics inherent in the design of the BIOS flow standard (especially the BIOS "Low Flow" cell). Consequently, the accuracy of flow rates obtained when calibrating MFCs with the BIOS should be empirically confirmed by inter-comparing the BIOS-indicated flow rate with an alternative flow standard. If discrepancies between the two flow standards exceed ± 2% at any flow setting, the BIOS should *not* be used in calibrating that particular model MFC.

4.1.2.2 Frequency of Calibrating Flow Standards

Following is the recommended minimum interval for calibrating (or "certifying") flow standards used for calibration of gas dilution calibrators:

- Hastings HBM-1A Bubble Meter: At time of manufacture or once thereafter

- "Transfer Standard Grade" Mass Flow Meter: every six months
- BIOS Dry Cal Flow Meters: once every 12 months
- Reference Temperature Standard: once every 12 months
- Reference Barometric Pressure Standard: once every 12 months

Additionally, flow standards should be re-calibrated whenever inter-comparison with an equivalent flow standard of known accuracy exceeds ± 2% (the Hastings Bubble Meter is usually best for this purpose), or if their proper operation is believed to be suspect.

4.2 Calibration of Gas Dilution Calibrators Using the Hastings HBM-1A Bubble Meter

The Hastings Mini-Flo Calibrator, Model HBM-1A is a system for precisely measuring the flow rates of gases using a method of volumetric displacement. When used in conjunction with a certified barometer, thermometer and stopwatch, it is a suitable test apparatus for calibrating flow controllers with NIST-traceability. The Model HBM-1A contains a set of three, numbered precision glass tubes, graduated in cubic centimeters (cc). Each tube has a different volume (0-10, 0-100, 0-1000 cc) and is traceable to the National Institute of Standards (NIST). Each tube can be fitted in a glass base (GB-1), which contains a water-based solution with a high surface tension. The mating surfaces of all tubes and the GB-1 base assembly feature standard, laboratory-grade tapered ground glass fittings which assure an air-tight connection.

During calibration of the MFC under test, (i.e., either the air channel or gas channel MFC in the TAPI T700), the gas stream from the calibrator output port is directed into the glass base of the HBM-1A. The gas stream flows from the base into the graduated tube, and then passes out through the open top of the graduated tube. The GB-1 is fitted with a squeeze bulb for momentarily raising the level of the solution in the base to block the entrance to the graduated tube. When the bulb is released the liquid level drops, and a film of the solution remains across the flow passage. The gas stream from the flow controller under test forces this film up the graduated tube. The surface tension of the liquid solution keeps the film intact; the net effect is a bubble defined by the cross-sectional area of the graduated tube, which traverses the length of the tube at a rate proportional to the flow controller gas flow rate. The bubble film closely approximates a frictionless piston.

By using a certified stopwatch to measure the time the film requires to travel through the demarcated volume of a given tube, the volumetric flow rate of the gas can be calculated. The volumetric gas flow rate can then be standardized (i.e., converted) to a mass flow rate (that is, a volume flow referenced to standard pressure and temperature conditions, which are 760 mmHg and 298 K). Corrections for water vapor pressure, ambient temperature, and atmospheric pressure are made by using the certified barometer, thermometer and water vapor table. (Table 6-1 presents correction factors for the vapor pressure of water.)

4.2.1 Assembly of Calibration Apparatus

Remove the Glass Base (GB-1) and Support Stand (BMS-1 assembly) from the case and place it on a level surface. Fill the glass base with a solution of clean, distilled water mixed with Ivory soap so that the liquid level is approximately 2" high in the base.

Select the proper capacity tube for the gas flow rate to be measured. The tube capacity selected should ensure that the time for the liquid film to travel the length of the graduated scale is approximately 0.2 minutes or longer. A clean plastic squeeze bottle should be filled with clean, distilled water and used to wet the HMB-1A glassware at all connection points, such as the ground glass joint between the tube and the base, and the hose connection. The inside surface of the glass tube should also be wetted. Connect one end of a length of rubber tubing to the hose connection on the glass base. The HBM-1A calibration apparatus is now ready for operation.

Connect the other end of the rubber tubing to a short length of 1/4 inch O.D. Teflon tubing. Connect the other end of the Teflon tubing directly to the MFC output port to be calibrated using a 1/4 inch Swagelok fitting. See Section 8.2.1 of the TAPI T700 Operation Manual for the location of the MFC outlet ports. Ensure all tubing connections are air-tight. Ensure the temperature and pressure of the room in which the calibration is being performed are accurately measured with a certified thermometer and barometric pressure standard. It is highly recommended that the calibration environment be free of drafts or strong air currents, and that the temperature is within the range of 20^{o} to 30^{o}C, and controlled within $\pm 2^{o}$C.

4.2.2 Calibration Procedure

1) Turn the TAPI T700 gas dilution calibrator on and allow the calibrator to warm up at least one hour. No gas flow is necessary during the warm up period.

2) To calibrate the AIR channel, connect a well-regulated zero air source to the rear inlet port of the TAPI T700 marked "DILUENT IN". Turn on the zero air source and adjust the output pressure to approximately 30 PSI.

3) Fill out the header information on Form 4-1, including date, technician name, identification of the calibrator and MFC under test, bubble tube serial number (S/N), thermometer, barometric pressure and elapsed time (stopwatch) standard identification information, most recent certification date for the thermometer, pressure and time standards, and current air temperature and pressure of the room in which the calibration is being performed.

4) Make sure that the T700 is in STANDBY mode. Press the SETUP button to enter the Primary Setup Menu. Press the MORE button to enter the Secondary Setup Menu. Press the DIAG button and ENTER PASSWORD by toggling the buttons to enter the correct password. Press the ENTR button to move to the SIGNAL I/O screen. In the SIGNAL I/O screen, continue to press the NEXT button until the MFC CONFIGURATION appears. Press the ENTR button to select the MFC to calibrate. Toggle the SET buttons to choose the desired MFC. Press the EDIT button to begin the calibration of the selected MFC. Toggle the PREV or NEXT buttons to scroll through the 20 calibration points. Select the highest flow drive voltage setting (5.000), toggle the OFF button to ON to start the flow and allow it to stabilize for 2 to 3 minutes. Record the stable TAPI T700 air channel display reading in the "MFM Rdg." space provided on Form 4-1 for Test No. 1.

5) Movement of the liquid film bubble through the selected HBM-1A graduated tube is initiated by quickly squeezing (and then releasing) the bulb on the GB-1 base assembly using the thumb and the index finger. The solution in the reservoir will momentarily rise and block the bottom opening of the tube. When the bulb is released a film will be left across the bottom opening of the tube. The film will move upward through the graduated tube due to the impetus provided by the gas flow from coming from the calibrator and pushing on the underside of the film. Note: If the film does not ride smoothly up the tube, or breaks before traversing the full length of graduated marking lines on the tube, thoroughly re-wet the inside of the tube. It may be necessary to re-wet the inside of the tube with water from time to time during the calibration process to maintain film integrity and smooth movement.

6) The stopwatch should be started at the exact moment that the film edge reaches the zero line located near the bottom of the tube.

   Note: To eliminate errors due to parallax, be sure to visually align the graduations on the front and back of the glass tube so that only one line is visible as the film passes the line.

7) The stopwatch should be stopped at the exact moment that the film edge reaches the top graduation line on the tube. The tube volumetric size, the TAPI T700 drive voltage display setting, the TAPI T700 display flow and the elapsed time the bubble film takes to traverse the length between the lowest and highest graduated lines on tube (as indicated by the stopwatch reading) should be recorded in the designated spaces provided on Form 4-1.

   Repeat Steps 5 through 7 above at least twice. Record the successive elapsed film travel times as T_1, T_2 (etc.) in the spaces provided on Form 4-1. The ratio of the volume traversed by the film to the period of time elapsed will be the volume flow in cc/minute, uncorrected for the vapor pressure of water, atmospheric pressure, or temperature.

8) Adjust the TAPI T700 air channel flow rate display setting (as indicated by the front panel display) to successively read "10.0", "9.0", "8.0", "7.0", "6.0", "5.0", "4.0", "3.0", "2.0", and "1.0". For each of these stable display flow rate settings, repeat Steps 4 through 7 above and record the corresponding test data on Form 4-1. The test data associated with the display flow rate setting of "10.0" should be recorded in the spaces denoted as Test No. 1 on Form 4-1; the test data associated with the display setting of "9.00" should be recorded in the spaces denoted as "Test No. 2" on Form 4-1, and so on, so that the test data for TAPI T700 flow rate display setting of "1.00" is recorded in the spaces denoted as "Test No. 10" on Form 4-1, for a total of 10 tested flow rates evenly distributed across the air channel MFC's range. **All MFC flow rate settings used for calibration purposes must be ≥10% and ≤100% of the manufacturer's stated full scale measurement range of that MFC (e.g., for a MFC with a stated full scale range of 0 to 20 SLM, all flow settings used for calibration purposes should be within the range of 2 to 20 SLM).**

9) Following obtaining 10 test flow rates for the air channel MFC, the MFC for the gas channel must be calibrated. A separate Form 4-1 should be used to record the gas channel MFC calibration data.

10) Install a regulator on a cylinder of pressurized calibration gas which has a balance gas of nitrogen or air. Connect the output of the regulator to the gas channel inlet fitting on the rear of the TAPI T700, open the cylinder and regulator valves, and adjust the regulator output pressure to approximately 30 PSI. Ensure that the TAPI T700 has been allowed a warm up period of at least one hour. Fill out the heading information on the Form 4-1 which is being used to record the gas channel calibration test data as instructed in Step 3 above.

11) Set the TAPI T700 gas channel flow rate to the highest front panel LED display setting (50.0) and allow it to stabilize for 2 to 3 minutes.

12) Repeat Steps 5 through 8 above for calibration tests for the gas channel. The successive gas channel LED display flow rate settings are: 50.0, 45.0, 40.0, 35.0, 30.0, 25.0, 20.0, 15.0, 10.0, and 5.0 for a total of 10 flow rate test points evenly distributed across the range of the gas channel mass flow-controlled flow controller.

4.2.3 Mass Flow Rate Calculations

1. The volumetric flow rate of each test point for each MFC must be calculated for each test point and then corrected to standard temperature and pressure conditions to obtain mass flow rates in standard cubic centimeters per minute (sccm).

   Equation 1 below is used to calculate the volumetric flow rate for each test point and simultaneously correct the volumetric flow rate to standard temperature and pressure conditions.

$$sccm = \frac{Vol}{T} \times \frac{298}{760} \times \frac{P_b - P_r}{(273 + TEMP_{°C})} \qquad \textbf{\textit{Equation 1}}$$

where:

- *Vol* = volume of graduated tube used in cubic centimeters (e.g.; 10cc, 100cc or 1000cc)
- *T* = the average time (in minutes) as determined by averaging the three (or more) elapsed times recorded for each gas flow test point on Forms 4-1.
- P_b = atmospheric pressure (in mmHg) in the room in which the calibration was performed.
- *Temp* = air temperature (in ^{o}C) of the room in which the calibration was performed.
- P_r = vapor pressure of water for the room air temperature recorded during the calibration (reference Table 4-1 to determine this value).
- *sccm* = flow rate (in standard cubic centimeters per minute) corrected to EPA standard conditions for temperature and pressure (i.e., 298^{o}K and 760

mmHg, respectively).

For each flow rate test point, calculate and record in the spaces provided on Form 4-1 the actual measured flow rate in sccm.

2. A linear regression analysis is now performed (separately) on the air channel MFC test data and the gas channel MFC test data. The TAPI T700 displayed drive voltage settings recorded for each test point on Form 4-1 are used as the "x" factor and the associated mass flow rate (calculated for that setting in Step 1, above) as the "y" factor. The linear regression analysis for the air and gas channels will have 10 pairs of data points.

3. Record the slope, intercept and correlation resulting from the linear regression analysis for the air channel and gas channel in the spaces provided on Form 4-1. Calculate the Indicated Flow values for each MFC LED display setting ("x") and record these results in the spaces provided on Form 4-1. Indicated flow rate values are the flow rates ("y") predicted from the results of the linear regression analysis, and can be simply calculated by using the "y'" (prime) function on a TI-68 calculator. If this option is not available, then calculate the indicated flow rate values using Equation 2 below:

$$y = mx + b \qquad \textbf{\textit{Equation 2}}$$

where: y = indicated MFC flow rate (sccm) for a given front panel flow rate display drive voltage setting on the T700 calibrator
x = TAPI T700 flow rate display setting
m = the slope resulting from the linear regression analysis performed using the calibration test data for that MFC
b = the intercept resulting from the linear regression analysis performed using the calibration test data for that MFC

4. Next, calculate the percent difference between the indicated flow (sccm) and the known flow (sccm) using Equation 3. The maximum allowable deviation from the best fit line is ± 2%. Be sure to record all information on Form 4-1.

$$\frac{Indicated\ Flow_{sccm} - Known\ Flow_{sccm}}{Known\ Flow_{sccm}} \times 100 \qquad \textbf{\textit{Equation 3}}$$

4.2.4 Updating Dilution Calibrator Set Point and Flow Rate Settings in the Calibrator

After the MFCs have been calibrated, the dilution calibrator set points and flow rates spreadsheet should be updated along with any programmed sequences in the calibrator and the data logger. Refer to Section 4.4 for the procedure to update the gas flow rates in the calibrator's programmed sequences and the corresponding gas concentrations in the calibrations sequences of the data logger.

4.2.5 Cleaning the Glassware

The glassware should be periodically cleaned to remove any residue which collects due to evaporation of the solution on the glass.

The glass can be cleaned by washing in soapy water, rinsing thoroughly, and drying.

TABLE 4-1 - VAPOR PRESSURE OF WATER (P_b)

Temp °C	P_b	Temp °C	P_b
20.0	17.535	23.6	21.845
20.1	17.644	23.7	21.978
20.2	17.753	23.8	22.110
20.3	17.864	23.9	22.244
20.4	17.974	24.0	22.377
20.5	18.086	24.1	22.513
20.6	18.197	24.2	22.648
20.7	18.310	24.3	22.785
20.8	18.422	24.4	22.922
20.9	18.536	24.5	23.060
21.0	18.650	24.6	23.198
21.1	18.765	24.7	23.337
21.2	18.880	24.8	23.476
21.3	19.000	24.9	23.616
21.4	19.113	25.0	23.756
21.5	19.231	25.1	23.898
21.6	19.349	25.2	24.039
21.7	19.468	25.3	24.183
21.8	19.587	25.4	24.326
21.9	19.707	25.5	24.472
22.0	19.827	25.6	24.617
22.1	19.949	25.7	24.765
22.2	20.070	25.8	24.913
22.3	20.193	25.9	25.061
22.4	20.316	26.0	25.209
22.5	20.441	26.1	25.359
22.6	20.565	26.2	25.509
22.7	20.690	26.3	25.661
22.8	20.815	26.4	25.812
22.9	20.942	26.5	25.965
23.0	21.068	26.6	26.117
23.1	21.196	26.7	26.272
23.2	21.324	26.8	26.426
23.3	21.454	26.9	26.583
23.4	21.583	27.0	26.739
23.5	21.714		

4.3 Calibration of Gas Dilution Calibrators Using the BIOS DC-2M Dry Cal Flow Meter

The BIOS Dry Cal Flow Meter, Model DC-2M is a system for precisely measuring the flow rates of gases using a method of volumetric displacement. The Dry Cal DC-2M incorporates both a temperature and pressure transducer, allowing the instrument to convert the measured volumetric flow rate to equivalent flow rate at STP. The Dry Cal DC-2M is a simple-to-use, battery-powered portable primary flow meter with an accuracy of ±1%. Annual factory calibration is recommended for maintaining traceability to the National Institute of Standards (NIST). The DC-2M can be used to measure gas flow rates from either a vacuum flow source (connected to the flow cell outlet port) or a pressure flow source (connected to the flow cell inlet port). Using proprietary, near-frictionless piston technology, the Dry Cal DC-2M combines high accuracy with speed and convenience. The Dry Cal consists of two primary sections. The base contains the electronics, microprocessor, temperature and pressure transducers, while the flow cell performs the physical measurements of flow. The base has an opening on its upper surface into which the flow cell is installed. The front of the base is angled for easy reading of the LCD display and includes a Power On/Off switch and Charge LED indicator. Below these are 4 white push-button switches. Volumetric flow readings are obtained with the push of a button. The Dry Cal can be set to take flow readings automatically, or manually one reading at a time. With each reading, both the volumetric and equivalent STP flow rates are automatically displayed on the four-line LCD display. The DC-2M can be programmed for up to 99 readings in an averaging sequence, useful for reproducibility studies.

The Dry Cal is a true primary gas standard. The time required for a frictionless piston to traverse a known volume is precisely measured and an internal computer calculates the flow. The accuracy of the instrument is built into its dimensions, sensors and timing crystal. When in use, gas flows from the inlet fitting through the internal cell valve to the outlet fitting. When a reading is begun, the valve closes and gas is diverted into the flow-measuring cell. The piston rises at the rate of gas flow. A photo-optic sensor reads a precision encoder attached to the piston and the time between encoder windows is measured by a crystal clock after a suitable acceleration interval. When a reading is completed, the valve is opened and the piston resets. The DC-2M instantaneously displays the flow reading on its LCD display.

4.3.1 Assembly of Calibration Apparatus

The Dry Cal accepts three interchangeable flow measurement cells, each having a different flow measurement range. The “high” flow cell is used to measure flow rates from 0.5 to 30 liters per minute (LPM). The “medium” flow cell is used to measure flow rates from 0.1 to 5 LPM. The “low” flow cell is used to measure flow rates from 10 to 300 milliliters (mL). Select the proper flow cell for the gas flow rate to be measured. Position the selected flow cell into the electronics base opening with its top label facing upwards. Rotate the cell back and forth gently to locate the 9 pin connector. When the cell no longer turns and the connector is engaged, press firmly downward. When the power is turned on, the Dry Cal electronics will sense which cell is installed and display the appropriate readings for that cell. **The BIOS power switch should always be in the OFF position when changing flow cells.** To remove a flow cell, turn the power off, grasp the flow cell firmly by the cylinder and wiggle gently upward and out of the base.

Connect one end of a length of rubber tubing to the BIOS flow cell INLET (pressure) port. Connect the other end of the rubber tubing to a short length of 1/4 inch O.D. Teflon tubing. Connect the other end of the Teflon tubing directly to the MFC output port to be calibrated using a 1/4 inch Swagelok fitting. Leave the outlet (suction) port of the Dry Cal open to ambient atmospheric pressure. See Section 8.2.1 of the TAPI T700 Operation Manual for the location of the MFC outlet ports. Ensure all tubing connections are air-tight. To convert the Dry Cal DC-2M volumetric flow rate measurements to equivalent flow rates at STP, external temperature and pressure standards may be used as an alternative to the DC-2M's internal temperature and pressure standards. If this is the case, use a certified thermometer having an accuracy of ±0.1 ^{o}C and barometric pressure standard having an accuracy of ±0.23 mmHg (±0.3mb). It is highly recommended that the calibration environment be free of drafts or strong air currents, and that the temperature is within the range of 20^{o} to 30^{o}C, and controlled within ±2^{o}C.

4.3.2 Calibration Procedure

1) Turn the TAPI T700 gas dilution calibrator on and allow the calibrator to warm up at least one hour. No gas flow is necessary during the warm up period.

2) To calibrate the AIR channel, connect a well-regulated zero air source to the rear inlet port of the TAPI T700 marked "DILUENT IN". Turn on the zero air source and adjust the output pressure to approximately 30 PSI.

3) Fill out the header information on Form 4-3, including date, technician name, identification of the calibrator and flow controller under test, BIOS Base and Flow Cell serial number (S/N), thermometer and barometric pressure standard identification information, most recent certification date for the thermometer and pressure standards, and current air temperature and pressure of the room in which the calibration is being performed.

4) Make sure that the T700 is in STANDBY mode. Press the SETUP button to enter the Primary Setup Menu. Press the MORE button to enter the Secondary Setup Menu. Press the DIAG button and ENTER PASSWORD by toggling the buttons to enter the correct password. Press the ENTR button to move to the SIGNAL I/O screen. In the SIGNAL I/O screen, continue to press the NEXT button until the MFC CONFIGURATION appears. Press the ENTR button to select the MFC to calibrate. Toggle the SET buttons to choose the desired MFC. Press the EDIT button to begin the calibration of the selected MFC. Toggle the PREV or NEXT buttons to scroll through the 20 calibration points. Select the highest flow drive voltage setting (5.000), toggle the OFF button to ON to start the flow and allow it to stabilize for 2 to 3 minutes. Record the stable TAPI T700 air channel display reading in the "MFM Rdg." space provided on Form 4-3 for Test No. 1.

5) Connect the appropriate flow cell into the BIOS base and turn the BIOS Dry Cal on. The start-up sequence will indicate on the display. Immediately following the Start-Up Screen, the DC-2M Main Menu will appear. If the technician plans on using the BIOS-indicated

flow rates *at STP*, ensure the BIOS reference temperature for STP is set to “25^{o}C” (do *not* use “0^{o}C”). The blinking cursor will highlight the “R” of the “Run” selection. Press the Enter button. The Run screen will indicate on the display. Press the Enter button again. The first flow reading will be indicated. Air flow calibration readings can be taken either one at a time, or averaged over a set number of consecutive readings. Five sets of a series of ten averaged consecutive readings should be used to obtain flow data for the calibration. To take averaged sequence readings, press the RESET button to clear the display. Press the BURST button and the Dry Cal will perform a series of continuous measurements and display the average STP (and volumetric) flow rate for those measurements.

Record the following in the designated spaces provided on Form 4-3:

a) The TAPI T700 drive voltage display setting;

b) The BIOS Dry Cal averaged flow rate at STP in standard liters per minute (Sl/m) *or* volumetric flow rate in liters per minute (l/m).

c) If the BIOS-indicated volumetric flow rate is used (as opposed to the flow rate at STP), then also record the ambient temperature and barometric pressure indicated by the external temperature and pressure standards at the time the flow measurement is obtained.

Repeat Step 5 above at least twice. Record the successive averaged flow rates (volumetric or at STP) as F_1, F_2 (etc.) in the spaces provided on Form 4-3. The average flow rate will be the flow in standard liters per minute (Sl/m) *or* volumetric flow rate in liters per minute (l/m). If *volumetric* flow rates were recorded from the BIOS, each averaged flow rate will need to be corrected to the equivalent flow rate at standard conditions of temperature and atmospheric pressure in accordance with subsection 4.3.3 Step 1 (below).

6) Adjust the TAPI T700 air channel flow rate display setting (as indicated by the front panel display) to successively read "10.0", "9.0", "8.0", "7.0", "6.0", "5.0", "4.0", "3.0", "2.0", and "1.0". For each of these stable display flow rate settings, repeat Steps 4 and 5 above and record the corresponding test data on Form 4-3. The test data associated with the display flow rate setting of "10.0" should be recorded in the spaces denoted as Test No. 1 on Form 4-3; the test data associated with the display setting of "9.00" should be recorded in the spaces denoted as "Test No. 2" on Form 4-3, and so on, so that the test data for TAPI T700 flow rate display setting of "1.00" is recorded in the spaces denoted as "Test No. 10" on Form 4-3, for a total of 10 tested flow rates evenly distributed across the air channel MFC's range. **All MFC flow rate settings used for calibration purposes must be ≥10% and ≤100% of the manufacturer’s stated full scale measurement range of that MFC (e.g., for a MFC with a stated full scale range of 0 to 20 SLM, all flow settings used for calibration purposes should be within the range of 2 to 20 SLM).**

7) Following obtaining test flow rates for 10 different flow rate settings spanning the range of the air channel MFC, the MFC for the gas channel must be calibrated. A separate Form 4-3

must be used to record the gas channel MFC calibration data.

8) Install a regulator on a cylinder of pressurized calibration gas which has a balance gas of nitrogen or air. Connect the output of the regulator to the gas channel inlet fitting on the rear of the TAPI T700, open the cylinder and regulator valves, and adjust the regulator output pressure to approximately 30 PSI. Ensure that the TAPI T700 has been allowed a warm up period of at least one hour. Fill out the heading information on the Form 4-3 which is being used to record the gas channel calibration test data as instructed in Step 3 above.

9) Set the TAPI T700 gas channel flow rate to the highest front panel LED display setting (50.0) and allow it to stabilize for 2 to 3 minutes.

10) Repeat Steps 4 through 7 above for calibration tests for the gas channel. The successive gas channel LED display flow rate settings are: 50.0, 45.0, 40.0, 35.0, 30.0, 25.0, 20.0, 15.0, 10.0, and 5.0 for a total of 10 flow rate test points evenly distributed across the range of the gas channel mass flow-controlled flow controller.

Note that the BIOS Dry Cal will display flow rates measured for the gas channel MFC in *milli*liters per minute (Sml/m or ml/m), *not* liters per minute (Sl/m or l/m). The Excel spreadsheet version of Form 4-3 will automatically convert milliliter per minute flow rates to equivalent flow rates expressed in liters per minute. This is necessary because the T700 calibrator references *all* flow rates (for both the air MFC and gas MFC) as liters per minute. To do this conversion manually, simply divide any BIOS-indicated flow rate expressed in Sml/m or ml/m by 1,000.

4.3.3 Flow Rate Calculations

1. If *volumetric* flow rates were recorded from the BIOS, each averaged flow rate will need to be corrected to the equivalent mass flow rate at standard conditions of temperature and atmospheric pressure (Sl/m).

Equation 1 below is used to correct volumetric flow rate to equivalent mass flow rate at standard conditions of temperature and atmospheric pressure.

$$slm = Flow_{vol} \times \frac{298}{760} \times \frac{P_a}{(273 + TEMP_{℃})} \qquad \textbf{\textit{Equation 1}}$$

where:

$Flow_{Vol}$ = average volumetric flow rate recorded for each test point. The average volumetric flow rate is the arithmetic sum of all of the flow rates recorded for that test point divided by the number of test points.

Pa = atmospheric pressure (in mmHg) in the room in which the calibration was performed.

Temp = air temperature (in ^{o}C) of the room in which the calibration was performed.
Sl/m = flow rate (in standard liters per minute) corrected to EPA standard conditions for temperature and pressure (i.e., 298^{o}K and 760 mmHg, respectively).

For each flow rate test point, calculate and record in the spaces provided on Form 4-3 the actual measured flow rate in Sl/m.

2. Separate linear regression analyses are now performed on the air channel MFC test data and the gas channel MFC test data. The TAPI T700-displayed drive voltage settings recorded for each test point on Form 4-3 are used as the "x" factors and the associated mass flow rate (calculated for that setting in Step 1, above) as the "y" factors. The linear regression analysis for the air and gas channels will have 10 pairs of data points.

3. Record the slope, intercept and correlation resulting from the linear regression analysis for the air channel and gas channel in the spaces provided on Form 4-3. Calculate the Indicated Flow values for each MFC drive voltage setting ("x") and record these results in the spaces provided on Form 4-3. Indicated flow rate values are the predicted flow rates (y′) from the results of the linear regression analysis, and can be simply calculated by using the y′ (“y prime”) function on a two-variable statistical calculator. If this option is not available, then calculate the indicated flow rate values using Equation 2 below:

$$y' = mx + b$$

where:

y' = indicated MFC flow rate (Sl/m) for a given front panel flow rate display drive voltage setting on the T700 calibrator
x = TAPI T700 flow rate display setting
m = the slope resulting from the linear regression analysis performed using the calibration test data for that MFC
b = the intercept resulting from the linear regression analysis performed using the calibration test data for that MFC

4. Next, calculate the percent difference between each indicated flow (in Sl/m) and the corresponding known flow (in Sl/m) using Equation 3. The maximum allowable deviation of the indicated flow from the known flow is ± 2%. Be sure to record all information on Form 4-3.

$$\frac{(Indicated\ Flow_{slm} - Known\ Flow_{slm})}{Known\ Flow_{slm}} \times 100 \qquad \textbf{\textit{Equation 3}}$$

4.3.4 Updating Dilution Calibrator Set Point and Flow Rate Settings in the Calibrator

After the MFCs have been calibrated, the dilution calibrator set points and flow rates spreadsheet should be updated along with any programmed sequences in the calibrator and the data logger.

Refer to Section 4.4 for the procedure to update the gas flow rates in the calibrator's programmed sequences and the corresponding gas concentrations in the calibrations sequences of the data logger.

4.4 Updating Dilution Calibrator Set Point and Flow Rate Settings in the Calibrator

Updating Form 4-4: Dilution Calibrator Set Points and Flow Rates, the programed sequences in the T700 calibrator, and the expected gas concentrations in the data logger is critical to accurate calibration gas generation. Form 4-4: Dilution Calibrator Set Points and Flow Rates should be updated with the slope and intercept values derived from the linear regression analysis obtained for the gas and dilution air channels above. The resulting calibrator set points must be updated in the programmed sequences in the calibrator and the expected gas concentrations must be updated in the data logger's calibration subsection of each analyzer's data channel. Follow the procedure in Section 3.2.4.2 of this SOP to update the programmed sequences in the calibrator with new set points. Additionally, update the expected gas concentrations in the data logger's calibration data table.

5. PRIMARY CALIBRATION

The purpose of a primary calibration is to establish the relationship between actual pollutant concentrations input to the analyzer (in ppm, ppb, ug/m^3, etc.) and the measurement system's response (i.e., chart recorder readings, output volts, digital output, etc.). This relationship is used to convert subsequent analyzer response values to corresponding pollutant concentrations until superseded by a later calibration of the analyzer.

5.1 Equipment And Materials

(a) TAPI T700 Operator Manual

(b) A reference (NIST-traceable) gas dilution calibrator (TAPI T700 calibrator or equivalent).

(c) Clean, dry zero air source ("TAPI 701" zero air supply or equivalent).

(d) Certified EPA Protocol G-1 compressed gas standard referenced to NIST-SRM.

(e) Dual-stage, stainless-steel, high-purity gas regulator (CGA 660).

(f) FEP Teflon tubing and stainless steel or Teflon compression fittings (for effecting leak-free interconnections for gas delivery between the zero air supply, compressed gas standard, dilution calibrator and analyzer sample inlet).

(g) Certified voltmeter (NIST-traceable) with a minimum resolution of 4 digits and a minimum accuracy of ± 0.001 VDC (e.g., Fluke 287 or equivalent).

(h) Texas Instruments T.I. 60 calculator (or equivalent).

(i) Multi-point Calibration Form (Form 5-1). Example at end of this SOP.

5.2 Frequency

(a) Initial installation of an analyzer.

(b) Relocation of an analyzer.

(c) Component failure that might affect analyzer's calibration.

(d) Level 1 zero/span drift limits are exceeded (see Table 4-1).

(e) Failure of a performance audit (see Table 4-1).

(f) At least once every six months, even if Level-I zero/span and precision checks show analyzers to be well within specified control limits.

5.3 Analyzer

(a) Calibrations will be performed on-site.

(b) Analyzer will be in its normal sampling mode and test gas atmospheres will pass through all filters, scrubbers, conditioners, and all other components used during normal ambient sampling and as much of the ambient air delivery system as is practicable.

(c) Unless the calibration data are obtained to assess "As Found" (unadjusted) analyzer response, all maintenance and any operational adjustments to the analyzer should be completed prior to running the calibration points. If the calibration is being performed on a properly-functioning analyzer that is currently producing data for the monitoring program, an "As Found" (unadjusted) Precision/Zero/Span (Level-I) check MUST be performed first, and the unadjusted analyzer response documented (refer to Section 6 in this SOP for detailed procedures for performing Level 1 zero/span and precision checks).

5.4 Test Gas Concentrations

Test gas concentrations delivered to the analyzer for a multipoint calibration will consist of a "zero" concentration (i.e., $\leq$ 1 ppb of the pollutant gas present in the gas stream) and at least four upscale test gas concentrations equally spaced over the analyzer's operating range. The highest test gas input concentration should fall within 70% ~ 90% of the analyzer's full scale operating range.

5.5 Multi-Point Calibration Procedure

(a) Fill out the heading information on the analyzer's Multi-point Calibration Form (see Form 5-1 at end of this SOP) with the models and serial numbers of the calibrator and zero air generator used, analyzer model and serial number, compressed gas standard cylinder I.D. number, concentration (ppm), pressure, and certification dates, the date of the calibration and other information pertinent to the calibration process.

(b) Allow the calibrator to warm up properly as described in the manufacturer's instruction manual. Purge the gas delivery system of the compressed gas standard to be used (see Step (c) below).

(c) The gas cylinder's two-stage, stainless steel regulator must always be purged prior to use for calibration to ensure it contains only gas from the cylinder-NOT ambient air. It is highly recommended that an initial series of purges be done 24 hours prior to use. A second series of purges is recommended immediately prior to use. Purging is accomplished by either of two methods:

- **Regulator Purge Method No. 1:** After the regulator is securely tightened on the cylinder, (ensure cylinder valve is closed), attach a vacuum pump to the regulator outlet using airtight fittings. Open the regulator output valve, and use the pump to evacuate the regulator to approximately -26 inches of Hg, as indicated on the regulator's output gauge. Close the regulator output valve, shut off the pump, and slowly open the cylinder valve to allow the regulator to become fully pressurized with the cylinder gas contents. Close the cylinder valve, open the regulator outlet valve, and repeat the evacuation process of the regulator, using the vacuum pump. This procedure should be repeated at least three times. The 1/8" tubing terminating in the stainless steel "quick-connect" fitting (which mates with the TAPI T700 inlet port) may now be attached to the regulator output fitting. After the tubing and quick-connect fitting are attached, open both the secondary valve of the regulator and the cylinder valve, and make the connection to the calibrator gas inlet port. Adjust regulator output pressure to read approximately 30 PSI, as indicated by the regulator output pressure gauge.

- **Regulator Purge Method No. 2:** Securely affix the regulator to the cylinder. Attach a 1/8" (O.D.) Teflon line (terminating in a l/8" quick-connect fitting) to the regulator output fitting. Open the cylinder valve and allow the regulator to fully pressurize with gas from the cylinder. Adjust the regulator output pressure to 30 PSI, as indicated on the regulator output pressure gauge. Close the cylinder valve and open regulator output valve fully (the regulator will stay pressurized, as the l/8" quick-connect fitting on the outlet line will not allow gas flow until the stem tip is depressed). Depress the stem tip of the "quick-connect" fitting against a convenient surface, allowing the gas in the regulator to slowly bleed off. Cease this gas flow (stop depressing "quick-connect" stem tip) when the output pressure gauge reading falls to 10 PSI (do NOT allow the outlet pressure to drop to 0 PSI). Re-pressurize the regulator fully by opening cylinder valve, closing it afterwards. Repeat the "bleeding" process by depressing the quick-connect valve stem tip. Reiterate this process 12-24 times, then make connections as usual to the gas dilution calibrator gas channel inlet port. Open the cylinder valve for gas flow.

Once the regulator has been purged, it should be left on the cylinder. The alternate procedure may then be employed (6-12 purges) just prior to any future use. The regulator and cylinder valves should always be fully closed unless in use. The regulator should remain pressurized at all times. **Assure gas cylinder pressure is greater than 100 PSI before use. Cylinders containing less than 100 PSI must not be used.**

(d) If the monitoring system is tied into a data collection system, provide the proper status information indicating that a calibration is being performed and that the data are to be excluded from the ambient measurements data base.

(e) **Prior to conducting the multi-point calibration, and prior to making any adjustments to a functional analyzer currently producing data for the ambient monitoring program, a precision and Level-I zero/span check ("P/Z/S" check) must first be performed (see Section 6 of this SOP).** This practice allows evaluation of analyzer "As Found" (unadjusted) response. If, however, the multi-point calibration is being performed immediately following major analyzer repairs or initial analyzer startup, an "As Found" P/Z/S check is not necessary.

If the "As Found" P/Z/S check zero response exceeds ± 10 ppb, or if the "As Found" P/Z/S check span response exceeds ±10% deviation from the known span input value, the analyzer should be subjected to a complete "As Found" multi-point calibration (i.e., obtain all multi-point calibration responses prior to making any adjustment to the analyzer). This unadjusted analyzer response data will be helpful in assessing historical data validity in such cases. "As Found" multi-point calibrations should be clearly labeled as such on Form 5-1. They are performed exactly as iterated in this section, with the following exceptions:

- No adjustments are made to the analyzer.
- All "As Found" multi-point calibration responses will be clearly labeled "As Found".

Assuming an "As Found" multi-point calibration was required, after it is completed, investigative and corrective action should take place to determine and correct the cause(s) for the excessive analyzer response drift. An NC/CA report must be completed to document the findings. After any problems are resolved, an "As Left" multi-point calibration must be performed, with adjustments made as necessary to the analyzer so that the "As Left" responses meet the acceptability criteria stated in Step (i) below. All "As Left" multi-point calibration documentation must be clearly labeled as such.

(f) Calculate the calibrator flow settings needed for the calibration system to produce the desired upscale concentrations of the test gas. The component gas flow rate and the diluent (zero) air flow rate will each have to be set, allowing control over the mixing ratio and the total calibration gas flow rate. At least four upscale test gas concentrations will be used in addition to zero. The upscale test gas concentrations will be in the following ranges:

Test Gas Concentration Ranges for Multipoint Calibration of Gaseous Pollutant Analyzers	
SO_2, TRS, O_3, NO, NO_2, NO_x	**CO**
80 -100 ppb	8 -10 ppm
200 – 250 ppb	20 – 25 ppm
300 – 350 ppb	30 – 35 ppm
400 - 450 ppb	40 - 45 ppm

Note: The Total Flow is defined depending upon system requirements. The minimum total flow should equal 150% of the flow requirements of all of the instruments to which the T700 will be supplying calibration gas. Example: If the T700 is expected to supply calibration gas mixtures simultaneously to a system composed of three analyzers each requiring 1 LPM, the proper Total Flow output should be set at: (1 + 1 + 1) x 1.5 = 4.500 LPM

1.) Determine the minimum total flow rate. Set the flow rate of the diluent gas equal to or greater than this flow rate.

2.) Determine the required flow rate of the component source gas using Equation 4:

$$GAS_{flow} = \frac{C_f \; x \; DIL_{flow}}{(C_i - C_f)} \qquad \textit{Equation 4}$$

Where:

C_f = the target concentration of the diluted gas (ppm)
C_i = the concentration of the source gas cylinder (ppm)
GAS_{flow} = the source gas flow rate in standard liters per minute (Sl/min)
DIL_{flow} = the flow of dilution air from the calibrator air channel in standard liters per minute (Sl/min)

Note: Use the current calibration curve of the gas dilution calibrator (as determined at six month intervals) to determine the appropriate diluent air channel and gas channel settings necessary to produce the flow rates calculated above. These flow rates and set points can be found on Form 4-4: Dilution Calibrator Set Points and Flow Rates.

(h) Set the calibration system to produce "zero" air: connect the output of the zero air generator to the “Air” input of the calibrator. Connect the output of the calibrator to the SAMPLE inlet of the analyzer through as much of the sample pneumatics as practical. Be certain that all filters and scrubbers usually in the system are included. Also be certain that the calibrator is always set to produce a minimum of 150% of the total flow so that it will exceed (by a minimum of 50%) the sample demand of the analyzer. Vent the excess calibrator output flow with a manifold or “tee” fitting with one leg of the “tee” left open to the exhaust system of the shelter. Keep the delivery pressure of the calibration gas to the analyzer as close to atmospheric pressure as possible. Do not subject the analyzer to positive or negative pressures of more than 0.5" H_2O.

(i) Make sure that the T700 is in STANDBY mode. Set the source gas and diluent flow rates for the span point using the GENERATE → MAN menu. Using the information from Equations 1 & 2 above, press GEN, MAN CAL GAS TYPE: ZERO. Toggle the gas type button to scroll through the available gas types that have been programmed into the T700 during the initial setup. Refer to the TAPI 700 Operation Manual if a gas type needs to be added. Continue pressing this key until the desired gas type appears. Press the ENTR button to accept the gas type and enter the CAL GAS FLOW rate by toggling the buttons to set the target gas flow. Press the ENTR button to accept the new gas flow rate. The DILUENT GAS FLOW screen should appear and toggle the buttons to set the target diluent flow rate, pressing the ENTR button to accept the new diluent gas flow rate setting. The T700 is now delivering calibration gas to the analyzer. When the analyzer responses have stabilized, note the output response in volts, as well as the corresponding ppm values indicated by the data acquisition system, or “DAS”, and recorder % full scale response.

Evaluate the initial analyzer zero response in accordance with the criteria set forth in Step (e) above and Table 4-1, and ensure appropriate "As Found" analyzer response checks have been obtained prior to making any analyzer adjustments. Assuming satisfactory completion of any "As Found" checks, document the analyzer’s initial calibration settings in the designated spaces provided on Form 5-1.

(j) Repeat step i for each of the additional midpoints.

(k) <u>Linear Regression Calculation</u>: After acceptable calibration results are achieved, use the TI 68 calculator (or equivalent) to perform a linear regression analyses on the analyzer responses. Use the <u>known</u> (input) concentrations from Steps (h), (i) and (j) above as the "X" factors for the regression analysis, and the corresponding DAS-indicated responses as the "Y" factors of the regression analysis. This will yield an equation in the form of Y = mX + b, where “m” is the slope and “b” is the intercept, for the analyzer response.

Record the slope, intercept, and correlation coefficient in the designated spaces provided on the calibration form. Check the linearity of the observed analyzer responses against the linear regression curve. Each point shall not exceed a deviation of ±2% of full scale when compared to the corresponding value obtained from the curve in order to qualify for acceptable linearity. If any point deviates from the curve by more than ±2% of full scale, then re-run the point(s) and perform a new linear regression analysis for the analyzer response.

(k) Conduct a manually-initiated span/zero check of the analyzer. Verify the zero and span response closely agrees with the observed analyzer zero response obtained during the calibration.

(l) Purge the T700 calibrator's internal pneumatics as well as any external pneumatic lines downstream from the calibrator of any residual test gas left in the system by activating the PURGE feature. The PURGE feature opens the diluent (zero) air inlet valve allowing zero air to flow into the calibrator from its external, pressurized source. It adjusts the diluent air MFC to maximum flow and adjusts all of the component gas MFCs installed in the calibrator to maximum flow to flush out the pneumatic system. The PURGE air is vented through the vent port of the rear panel of the instrument. To activate the PURGE feature, press The PURGE button in the GEN menu. Allow the system to purge for several minutes and stop the purge by pressing the STBY button to stop the purging process and place the T700 in STANDBY mode.

(m) Restore the monitoring system to normal ambient sample mode: disconnect the sample line from the reference calibrator's gas delivery line and re-connect it to the sample intake manifold. If the monitoring system is tied into a data collection system, provide the proper status information indicating that valid data is again being collected. Ensure that the calibrator has been left in STANDBY mode.

(n) Neatly record a complete synopsis of the calibration data (including any adjustments made) in that day's site logbook entry.

5.6 <u>Documentation</u>

(a) Completed Multi-point Calibration Forms are sent to the Enviroplan Consulting Data Management Department for review (include with regular monthly shipments of field data).

(b) Enter all results in site logbook in a neat, concise, and comprehensible format. Include any and all adjustments. This provides the permanent on-site record.

(c) See Section 4.6 for additional documentation requirements.

6. AUTOMATIC LEVEL 1 ZERO/SPAN AND PRECISION CHECK PROCEDURES

Data Quality Assurance requirements set forth in 40 CFR Part 58, Appendix B stipulate that precision checks are required to be made on automated gaseous pollutant analyzers used in air quality monitoring applications. The results of these checks are used as indicators of the quality of the monitoring data reported. “Level I” zero/span checks are made using NIST-traceable calibration standards and provide periodic, authoritative assessments of the conformance of an analyzer’s response with current calibration data.

The precision check requirement will be met by challenging the analyzer at a known input test gas concentration. The percent difference (Δ %) between the actual concentration indicated by the measurement system and the known concentration of each precision check gas concentration is used to assess the precision of the monitoring data.

A Level 1 zero/span check will be performed daily and also in conjunction with scheduled precision checks. The Level 1 check consists of a zero check gas and one-point span check gas of known concentration within the range of 70 to 90% of the analyzer’s full scale measurement range. The Level-I zero and span checks provide a method by which analyzer accuracy and calibration drift can be assessed and controlled. The percent difference (Δ %) between the actual concentration indicated by the measurement system and the known span input concentration is used to assess the degree of calibration control (or drift) of the monitoring system.

Collectively, these checks are informally referred to as “P/Z/S” checks. This check will be automatically initiated by the digital acquisition system once every week. The procedure for performing a manual P/Z/S check is described in the following sub-sections.

6.1 <u>Equipment</u>

(a) Analyzer Operation Manual

(b) Certified gas dilution calibration system (e.g., TAPI T700 calibrator with “TAPI 701E” Zero Air Supply, or equivalent)

(c) Certified (EPA Protocol G-1) cylinder referenced to NIST-SRM (used w/gas dilution calibrator and zero air generator).

(d) Dual-stage, stainless-steel, high-purity gas regulator (CGA 660).

(e) Certified voltmeter (NIST-traceable) with 4-digit display and minimum accuracy of ± 0.001 VDC (e.g., Fluke 287 or equivalent).

(f) FEP Teflon tubing and stainless steel or Teflon compression fittings (for effecting leak-free interconnections for gas delivery between the zero air supply, compressed gas standard, dilution calibrator and analyzer sample inlet).

(g) Texas Instruments TI-68 calculator or equivalent.

(h) SO2 Calibration Form (Form 5-1). An example of this form appears at the end of this SOP.

6.2 Frequency

(a) At least once every two weeks (automatically initiated weekly by DAS).

(b) When automatic daily zero/span check (“autocal”) control limits are exceeded (see Table 4-1).

(c) Prior to performing multi-point calibrations on functional analyzers currently producing data for an ambient air monitoring program.

6.3 Definitions

For this procedure, the following definitions apply.

(a) **Precision Check** - For this monitoring program, a precision check will consist of a dynamic response check of the analyzer at a NIST-traceable test gas input concentration. The results of all precision checks are used to compute precision of the data. A precision check must precede any adjustment to the analyzer.

(b) **Zero Check** - a dynamic response check of the analyzer to a "zero" air gas stream (i.e. contains less than 1 ppb of the respective pollutants).

(c) **Level-I Span Check** - a dynamic response check of the analyzer to a NIST-traceable test gas input concentration at 70-90% of full scale. This, together with the zero check, is used to evaluate the current calibration drift of the analyzer, and to determine the need for any adjustments.

6.4 Procedure To Conduct A Manual Level 1 Zero/Span And Precision Check

(a) Allow the calibrator to warm up properly as described in the Operation Manual. Make appropriate gas delivery line connections from the zero air source to the calibrator (all materials must be FEP Teflon or stainless steel). Connect the output of the calibrator to the sample inlet of the analyzer. Ensure a "tee" fitting (with one leg left open to the atmosphere) vent is incorporated at the connection of this line to the sample inlet so that gas is delivered to the analyzer at or near atmospheric pressure. Make certain the sample inlet connection incorporates as much of the sample delivery train as is practicable, including any and all filters or scrubbers normally used. Purge the gas delivery system of the gas standard to be used. (See Section 5, Step (c) for purge procedures.) It is highly recommended that the gas regulator and delivery line be attached to the gas standard 24 to 48 hours prior to use. The regulator should be subjected to a series of purges at this time and at least one additional series of purges prior to use. Ensure gas cylinder pressure is greater than 100 PSI. **Do not use a cylinder containing pressure less than 100 PSI.**

(b) Fill out the heading information on the analyzer's Calibration Form (see Form 5-1 at end of this SOP) with the models and serial numbers of the calibrator and zero air generator used, analyzer model and serial number, compressed gas standard cylinder I.D. number, concentration (ppm), pressure, and certification dates, the date of the calibration and other information pertinent to the calibration process Fill out the header information called out on Form 5-1. Access the analyzer's calibration factors in the **CALDAT** menu and record the analyzer's current **SLOPE** and **OFFSET** calibration settings in the designated spaces provided on Form 5-1.

(c) Supply the necessary status information to the data logger to exclude the test data from the data base.

(d) Use the following equations to calculate the designated test gas flow rates for precision point, Level 1 span point.

<u>Note:</u> The Total Flow is defined depending upon system requirements. The minimum total flow should equal 150% of the flow requirements of all of the instruments to which the T700 will be supplying calibration gas. Example: If the T700 is expected to supply calibration gas mixtures simultaneously to a system composed of three analyzers each requiring 1 LPM, the proper Total Flow output should be set at: (1 + 1 + 1) x 1.5 = 4.500 LPM

1.) Determine the minimum total flow rate. Set the flow rate of the diluent gas equal to or greater than this flow rate.

2.) Determine the required flow rate of the component source gas using the following formula:

$$GAS_{flow} = \frac{C_f \; x \; DIL_{flow}}{(C_i - C_f)} \qquad \textit{Equation 4}$$

Where:

C_f = the target concentration of the diluted gas (ppm)
C_i = the concentration of the source gas cylinder (ppm)
GAS_{flow} = the source gas flow rate in standard liters per minute (Sl/min)
DIL_{flow} = the flow of dilution air from the calibrator air channel in standard liters per minute (Sl/min)

(e) Use the current calibration curves of the gas and air MFCs in the gas dilution calibrator (as determined at 6-month intervals) to determine the appropriate diluent air channel and gas channel "display settings" needed to effect the flow rates calculated in Step (d) above.

(f) Generate a Level 1 Zero test gas concentration, making sure $TOTAL_{flow}$ exceeds the analyzer sample flow rate by at least 50%, following the procedure in Section 6.4.3.4 of the TAPI 700 Operation Manual. Scroll the **<TST TST>** keys to display the **A-CAL** and **A-DIL** test functions to view the actual gas flow rate and diluent (zero) gas flow rate being output by the calibrator. Allow the analyzer response to stabilize. This may take several minutes. Record the zero response of the analyzer measurement system as observed on the analyzer's output voltage (in volts) and the DAS response (in ppm). Record these responses in the designated spaces provided in the "As Found Response" data section of the precision/zero/span check form. **MAKE NO ADJUSTMENTS AT THIS TIME.**

(g) Generate a precision test gas concentration. (Again, ensure the calibrator's total flow rate exceeds the analyzer's sample flow rate by at least 50%) Scroll the **<TST TST>** keys to display the **A-CAL** and **A-DIL** test functions to view the actual gas flow rate and diluent (zero) gas flow rate being output by the calibrator. Allow the analyzer response to stabilize. This may take several minutes. Record the response of the measurement system as observed on the analyzer's output voltage (in volts) and the DAS response (in ppm). Record these responses in the designated spaces provided in the "As Found Response" data section of the precision/zero/span check form. **MAKE NO ADJUSTMENTS AT THIS TIME.**

(h) Repeat as in (g) for a Level 1 Span test gas concentration of approximately 70-90% full scale. Record the stable measurement system responses as described in Step (f). **MAKE NO ADJUSTMENTS AT THIS TIME.**

(i) Calculations:

(1.) Calculate the percent difference (Δ%) for each of the three upscale response points obtained in Steps (g), (h) and (i) above according to the formula:

$$\Delta\% = \frac{(Observed\ ppm - Known\ ppm)}{Known\ ppm}\ x\ 100 \qquad \textbf{\textit{Equation 5}}$$

(2.) Record the percent difference results (rounded to the nearest tenth of a percent) in the designated spaces provided in the "As Found Response" section of Form 5-1.

6.5 Control Limits For Level 1 Zero/Span Checks

6.5.1 Evaluate "As Found" Results

The control limits for "As Found" (unadjusted) Level 1 zero/span checks responses are as follows:

- Zero Response: ≤± 10 ppb
- Span Response: Δ% ≤ ±10% (compared to the known span gas input concentration).

If all "As Found" (unadjusted) responses are within the specified control limits, minor adjustments to the analyzer's **SLOPE** and/or **OFFSET** settings may be made to keep the analyzer's response well within the specified control limits. These adjustments may be warranted as a strategy for providing a high degree of assurance that the measurement system's response will remain within the control limits going forward. Any such adjustments, however, must be immediately followed by performance and documentation of an "As Left" (adjusted response) Level 1 zero/span check. Procedures for accomplishing this are presented in Section 6.5.2 below.

If any of the control limits are exceeded, a multi-point calibration is necessary (see Section 5). Furthermore, if the "As Found" Level 1 span response Δ% exceeded ±15%, or if the "As Found" Level 1 zero response exceeded ± 10 ppb, a complete unadjusted multipoint calibration should be performed and documented prior to performing an adjusted calibration. In any event, it is mandatory that "As Found" (unadjusted) precision, zero and span responses be obtained and documented prior to any adjustments taking place.

Before making any adjustment to the analyzer (either zero or span), however, it is prudent to examine all available information and make sure the analyzer calibration has really drifted. Subtle malfunctions of the calibrator can cause unnecessary adjustment of an analyzer and much unnecessary grief. This can be avoided by taking the extra time to be careful in performing Level 1 Zero/Span and Precision checks.

(a) Review the previous Level 1 zero/span and Precision Check results to see how much the analyzer has drifted since the last check. If excessive change (more than ±10%) has occurred, there may be a problem with the analyzer or calibrator. Investigative actions should be undertaken to assure both instruments are operating properly .**NOTE: If the calibration system is found to be the source of the problem, the precision/zero/span check just completed is invalid.**

(b) Refer to the data logger autocal reports for the analyzer and carefully examine the autocal results since the last Level-I Span Check. If the analyzer has drifted excessively, the trend should be apparent.

(c) Double check all calculations. Make sure the dilution calibrator flow calibration data and gas standard analysis you are using are current.

(d) Carefully examine all plumbing for dirt, leaks, crimps or other potential causes of erroneous readings.

(e) Check the analyzer's operating status readouts and compare these to historical records and the manufacturer's stated normal ranges. If a significant change is evident, the analyzer may have a problem. (Investigate to verify. Check the analyzer "Diagnostics" menu and Chapter 6 -"Troubleshooting"- in the manufacturer's Instruction Manual as an aid to resolving any operational problem with the analyzer.) Also, check the analyzer's sample line and particulate filter. Changing the filter element might solve the problem and eliminate the need for analyzer adjustment.

(f) Record all investigative findings and associated corrective actions (if any) in the field station log for future reference.

6.5.2 Analyzer Adjustments

(a) As previously stated, the control limit for unadjusted Level 1 span check results are ±10% of designated test gas concentrations. Similarly, the control limit for unadjusted zero responses are ± 10 ppb. If these limits are exceeded, a full multi-point (adjusted response) calibration of the analyzer is necessary (refer to Section 5 of this SOP).

<u>NOTE</u>: If the unadjusted span response exceeded ±15%, or the unadjusted zero responses exceed ± 10 ppb, a complete <u>unadjusted</u> multi-point calibration response should be performed <u>prior</u> to performing investigative actions to establish assignable cause for such drift, corrective actions and subsequent re-calibration. Additionally, an NC/CA Report Form must be completed by the network operator (see Section C of the QAPP).

(b) If the percent differences for all span responses are within ±5%, there is little need to make a span adjustment. If span response is >±5%, but ≤±10%, verify all calculations, settings, and proper operating status prior to making any adjustments. Adjust the analyzer span setting to obtain a reading within ± 5% (refer to Step (h) in Section 5.5 under "Multipoint Calibration Procedure" for correct span adjustment procedure).

(c) If an adjustment to the analyzer zero response is desired, or if a span adjustment was necessary in Step (b) above, repeat the zero check. The control limit for zero response is ± 10 ppb. If the initial "As Found" Level 1 zero check response was within this control limit, adjust the zero setting as needed to maintain acceptable zero response going forward (refer to Step (g) in Section 5.5 under the

"Multipoint Calibration Procedure" for instructions on zero adjustment). Recommended good practice is to maintain zero response within ± 5 ppb.

(d) Repeat and re-verify the adjusted span and/or zero responses as necessary until both responses are satisfactory. Record the final "As Left" (adjusted) values for the measurement system zero and span responses as described in Step (f) above for the analyzer output voltage and DAS indications in the designated "As Left SO_2 Response" spaces provided on Form 5-1.

(e) Finally, access the **CAL DATA** menu screen and record the final "As Left" (adjusted) values for the **SLOPE** and **OFFSET** settings in the designated spaces provided on Form 5-1.

(f) Restore the monitoring system to normal ambient sample mode: disconnect the sample line from the reference calibrator's gas delivery line and re-connect it to the sample intake manifold. If the monitoring system is tied into a data collection system, provide the proper status information indicating that valid data is again being collected.

(g) Enter date, time, and operator's initials on the strip chart at end of the P/Z/S check. Ensure all significant traces and adjustments are fully documented on strip chart. Neatly record a complete synopsis of the P/Z/S check results (including any adjustments made) in that day's site logbook entry.

6.6 Documentation

(a) Enter all results and activities in the site logbook. This provides the permanent on-site record.

(b) Calibration Form (Form 5-1) sent to Enviroplan Consulting's Data Management Department on a monthly basis.

7. ROUTINE OPERATION

During each scheduled site visit, the calibrator and support equipment (zero air supply, data logger, shelter temperature control system, sample train, etc.) should be inspected to verify proper operation. A thorough inspection of instrument operations will help locate potential problems before they have substantive effect and therefore help ensure proper instrument function between site visits.

Routine site visits shall be conducted at a minimum frequency of once per week. Two visits per week should be conducted in the event that telephone service to the site is not available to allow remote review of the data. Each site inspection should include the following:

7.1 Data Logger

(a) Check the logbook for instrument status noted during the previous site visit.

(b) Review the data logger record of all analyzer parameters back to the most recent, previous data logger inspection.

- Verify that automatic daily zero/span checks are within control limits.
- Verify that the characteristics of the data appear normal and reasonable.
- Make sure that the data logger time correlates with the actual time.

(c) During each site visit, record in the site logbook the date, current local standard time (LST), instrument status, and operator initials.

- Date
- Time check (LST) and any adjustments made to correct discrepancies relative to current LST and/or date.
- Instrument zero check responses (except for auto-cal traces)
- Instrument span check responses and associated known input test gas concentrations (except for auto-cal traces)
- For segments containing test traces, identification of the type of check performed (including designating “As Found”/”As Left” responses, as applicable).
- Periods of time that service or maintenance were performed
- Site and network names

- Unusual conditions or events (e.g., meteorology, industrial activity, fires, and shelter temperature problems) that could affect data interpretation.

- Any adjustments made.

7.2 <u>Analyzer</u>

(a) Perform and document all checks of analyzer internal operating status indications called out on the site check form (Form 7-1). Example form at end of this SOP.

(b) Check all electrical and pneumatic connections.

(c) Listen for unusual noises which might indicate a developing problem (e.g., pump going bad).

(d) Ensure the in-line sample particulate filter is replaced every two weeks, or more frequently if inspection warrants. Use only FEP Teflon membrane filters for this purpose.

7.3 <u>Other Support Equipment</u>

(a) <u>Calibrator</u> - Check all connections and verify correct current time and date display. Verify all status indications are correct. Verify that calibrator, analyzer and data logger-indicated current time and date match.

(b) <u>Sample delivery system and lines</u> - Check the system for integrity, condensation, and cleanliness. If there is any liquid (condensed) water present in any components of the sample air delivery system, document the finding in the “Comments” section of Form 7-1 and use a clean, lint-free, absorbent cloth and/or compressed air to thoroughly dry the affected components. Consult the Field Operations Supervisor or Project Manager to determine the need for and appropriate methods to prevent a recurrence. **Data will be invalidated for the 24-hour period preceding the detection of liquid condensate in the sampling train.**

(c) <u>Shelter temperature and control equipment</u>- Inspect all other equipment (heaters, air conditioners, etc.) for proper operation. Check and log site temperature (minimum and maximum) and reset min/max thermometer.

7.4 Documentation

(a) Fill out all of site check forms completely.

(b) Enter all activities performed in the site logbook. An entry must be made each time the site is entered. If all operations appeared normal, the logbook entry would contain at a minimum: Date, time of arrival (LST), minimum/maximum shelter temperature, monitoring system status (e.g., “all operations normal”), time of departure (LST) and operator's signature. All entries must be clear, complete, specific, legible, and accurate so that they can be used by other people at other times to evaluate all monitoring program field activities and data validity. Any NC/CA events, including associated investigative and corrective actions, should be clearly and concisely documented.

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8. PREVENTIVE AND CORRECTIVE MAINTENANCE

In order to ensure the reliable operation of monitoring equipment, and a high degree of valid data capture, a preventive maintenance program is essential. Preventive maintenance activities are based on the guidance contained in the manufacturers' operating manual and Enviroplan Consulting's cumulative experience in conducting ambient air monitoring programs.

The T700 has predictive diagnostic functions including failure warnings and alarms built into the calibrator's firmware that allow the determination of when repairs are necessary without performing painstaking preventative maintenance procedures. For the most part, the T700 calibrator is maintenance free, there are, however, a minimal number of simple procedures that when performed regularly will ensure that the T700 continues to operate accurately and reliably over its lifetime.

All maintenance performed must be entered in a chronological format in the site logbook and instrument maintenance log (see Form 8-1 at the end of this SOP). The instrument must be identified by make, model and serial number. Each entry must be dated and signed by the network operator.

8.1 Calibration Equipment

The primary calibration equipment used in conjunction with the monitoring systems analyzers is a TAPI T700 gas dilution calibrator and TAPI 701 zero air supply, together with a certified (EPA protocol G-1) compressed gas cylinder. This system is also the equipment used for the automatic daily zero/span check of the analyzer.

This equipment should be maintained according to the manufacturer's recommendations and instrument manual. Checks as noted on the site visit checklist should be conducted and followed-up accordingly. Enter all work performed in the chronological site logbook and in the instrument maintenance log.

Network operators must work in conjunction with the Enviroplan Quality Assurance Lab personnel to ensure that all reference calibrator components are NIST-traceable and kept certified according to schedule. All traceability and original calibration documentation is archived at Enviroplan Consulting's offices in Wayne, NJ.

8.2 Miscellaneous Support Equipment

Monitoring system support equipment such as the sample delivery train components, air conditioners, heaters, etc. must be inspected and cleaned periodically for continued proper operation.

The borosilicate glass sample intake probe and manifold should be inspected weekly for visible dirt. These components should be cleaned at least once per year or more frequently if visible dirt and ambient conditions warrant. Cleaning is typically effected using distilled water and bristle brushes only. For stubborn foreign matter, a detergent may be needed, however, all residue must be thoroughly rinsed off using distilled water and the components air-dried prior to re-installation.

Sample lines should be replaced when direct is visible. Exterior dirt should not be mistaken for dirt on the interior surface of sample lines. The associated replacement interval can vary greatly, depending on ambient conditions.

Air conditioner filters should be replaced at the beginning of each cooling season. The condenser coils should also be thoroughly washed at the same time.

The exterior of the shelter structure should be closely inspected at least once each year, preferably during the warm seasons. Structural or other mechanical problems should be repaired promptly. Missing rivets or gaps in seams can be repaired using a high-quality, outdoor-use rated silicone sealant compound (e.g., Dow-Corning Silicone II). Invisible roof leaks can be repaired by painting the roof with an industrial-grade epoxy paint.

Table 8-1 shows the maintenance schedule for the T700. Please note that in certain environments (i.e. dusty, very high ambient pollutant levels) some maintenance procedures may need to be performed more often than shown.

Table 8-1: T700 Maintenance Schedule

Item	Action	Frequency
Verify test functions	Record and analyze	Weekly or after any maintenance or repair
Pump diaphragm	No replacement required. Under normal circumstances the pump will last the lifetime of the instrument.	
Perform flow check	Verify flow of MFCs	Every six months
Perform leak check	Verify leak tight	Annually
Pneumatic lines	Examine and clean	Examine whenever cover is opened. Clean as needed, flowed by cal check.

9. TROUBLESHOOTING

The Model T700 is designed utilizing a modular approach. The internal components of the instrument are grouped into replaceable subassemblies to facilitate fault isolation and correction. Chapter 11 ("Troubleshooting") in the Operation Manual should assist the field operator in identifying the malfunctioning component or module. The faulty module can then be replaced, thus returning the instrument to monitoring as soon as possible. The defective module can then be repaired by a technician familiar with the mechanical aspects or electrical principle involved in its operation.

The T700 Dynamic Dilution Calibrator has been designed so that problems can be rapidly detected, evaluated and repaired. During operation, it continuously performs diagnostic tests and provides the ability to evaluate its operating parameters without disturbing monitoring operations. A systematic approach to troubleshooting will generally consist of the following four steps:

1. Note any warning messages and take corrective action as necessary.

2. Examine the values of all TEST functions and compare them to factory values. Note any major deviations from the factory values and take corrective action.

3. Use the internal electronic status LEDs to determine whether the electronic communication channels are operating properly.

    - Verify that the DC power supplies are operating properly by checking the voltage test points on the relay PCA.
    - Note that the calibrator's DC power wiring is color-coded and these colors match the color of the corresponding test points on the relay PCA.

4. Follow the procedures defined in Section 3.3.4 of the T700 Operation Manual to confirm that the calibrator's vital functions are working (power supplies, CPU, relay PCA, etc.). See Figure 3-5 and Figure 3-6 in the Operation Manual for general layout of components and sub-assemblies in the calibrator. See the wiring interconnect diagram and interconnect list in Appendix D of the Operation Manual.

The most common and/or serious instrument failures will result in a warning message being displayed on the front panel. Table 11-1 in the Operation Manual lists warning messages, along with their meaning and recommended corrective action. It should be noted that if more than two or three warning messages occur at the same time, it is often an indication that some fundamental sub-system (power supply, relay PCA, motherboard) has failed rather than indication of the specific failures referenced by the warnings. In this case, it is recommended that proper operation of power supplies (See Section 11.4.3), the relay PCA (See Section 11.4.7), and the motherboard (See Section11.4.11) be confirmed before addressing the specific warning messages.

The T700 will alert the user that a Warning Message is active by flashing the FAULT LED, displaying the Warning message in the Param field along with the **CLR** button (press to clear Warning message). The **MSG** button displays if there is more than one warning in queue or if you are in the TEST menu and have not yet cleared the message.

A digital multimeter capable of resolving 1 mV is recommended for troubleshooting the Model T700.

A supply of common parts is typically a part of the network inventory. This parts stock is determined by repair history for the model analyzer in use. If the analyzer incorporates any expendable or short-life components (recommended replacement frequency of one year or less), they are normally included as part of the network inventory, thus minimizing down time of the instrument.

In all circumstances, failure or malfunction of the instrument is to be reported promptly to the field supervisor and the Project Manager. A Non-Conformance/Corrective Action plan should be developed and implemented to resolve the problem as quickly as possible, so as to minimize any associated data loss (see Section C of the QAPP).

All actions associated with servicing or repairing the instrument will be summarized in the site logbook. A similar synopsis should appear in the "comments" section of the analyzer routine check form.

FORM 4-1:
MASS FLOW METER CALIBRATION FORM
Using Bubble Meter Flow Standard(s)

CALIBRATOR APPLICATION INFORMATION:		NETWORK:	PAMS	SITE:	
Calibrator Model/S/N:		Date:			
Calibration Site:	Wayne, NJ Quality Assurance Lab	Calibrated by:			
Barometric Pressure (Pa, in mmHg)		Cyl. No. & Cert. Date:	1288 (6-14-11)	Cyl. Vol. (cc)	1,000
Flow Standard Model:	Hastings HBM-1A	Cyl. No. & Cert. Date:	1288 (6-14-11)	Cyl. Vol. (cc)	10
Pressure Std. Model & S/N:	Setra 370 / 4493426	Temp. Std. Model & S/N:	Brooklyn Thermometer Co. 6660FC s/n311403		
Pressure Std. Cert. Date:	11/2/2010	Temp. Std. Cert. Date:	4/26/2011		

Check One: ______ Air Channel ______ Gas Channel

Avg Flow (sccm) = (Vol. * 298 * (P_a-P_r)) / ($T_{avg.}$ * 760 * T_a)

Where: Vol. Is bubble meter cylinder volume in cc; Pr is water vapor pressure in mmHg; Pa is ambient pressure in mmHg; Ta is ambient temperature in deg. K; and Tavg. Is average bubble traverse time in minutes (decimal)

(X) MFC Display Set Point	Bubble Traverse Times T_1 (minutes)	T_1 (seconds)	T_2 (minutes)	T_2 (seconds)	T_3 (minutes)	T_3 (seconds)	T_4 (minutes)	T_4 (seconds)	T_5 (minutes)	T_5 (seconds)	$T_{avg.}$ (minutes) T_2+T_3+T_4+	Amb. Temp. (Ta) (deg C)	Vapor Pressure H2O (Pr) (mmHg)	Cyl. Vol. (cc)	(Y) Avg. Flow (sccm)	(Y') Flow Rate From **Curve** (sccm)	Δ % (Y' - Y) Y
5.00											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
4.50											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
4.00											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
3.50											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
3.00											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
2.50											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
2.00											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
1.50											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
1.00											0.00			1,000	#DIV/0!	#DIV/0!	#DIV/0!
														1,000			

Slope = #DIV/0! **Intercept = #DIV/0!** **Corr. = #DIV/0!**

Comments: ______________________________

FORM 4-2
MASS FLOW METER CALIBRATION FORM
USING MKS MASS FLOWMETER ("MFM") STANDARDS

CALIBRATOR APPLICATION INFORMATION:		NETWORK:		SITE:
Calibrator Model/S/N:		Date:		
Calibration Site:		Calibrated by:		
AIR CH. Flow Std:	MKS 0358C (0-10 SLM)	GAS CH. Flow Std:	MKS 0358C (0-50 SCCM)	
AIR CH. Flow Std. S/N:	0258C08372481	GAS CH. Flow Std. S/N:	0258C08373481	
AIR CH. Flow Std. Cal Date:	02-07-01	GAS CH. Flow Std. Cal Date:	01-29-01	
AIR CH. Flow Std. Slope:	2.0040584600	GAS CH. Flow Std. Slope:	10.0360097000	
AIR CH. Flow Std. Intcpt:	-0.0121900000	GAS CH. Flow Std. Intcpt:	-0.2533200000	

DMM Model:	Fluke 8060A	DMM S/N:		DMM Cert. Date:	

AIR CHANNEL CAL DATA

(X) MFM Display Set Pt.	MKS VOLTS out	(Y) Avg. Flow (sccm)	(Y') Indicated Flow Rate From Regress. Curve (sccm)	Δ % (Y - Y') x 100 / Y'
5.00		-12.19	-12.19	0.0%
4.50		-12.19	-12.19	0.0%
4.00		-12.19	-12.19	0.0%
3.50		-12.19	-12.19	0.0%
3.00		-12.19	-12.19	0.0%
2.50		-12.19	-12.19	0.0%
2.00		-12.19	-12.19	0.0%
1.50		-12.19	-12.19	0.0%
1.00		-12.19	-12.19	0.0%
0.50			-12.19	#VALUE!

GAS CHANNEL CAL DATA

(X) MFM Display Set Pt.	MKS VOLTS out	(Y) Average Flow (sccm)	(Y') Indicated Flow Rate From Regress. Curve (sccm)	Δ % (Y - Y') x 100 / Y'
50.00		-0.25	-0.25	0.0%
45.00		-0.25	-0.25	0.0%
40.00		-0.25	-0.25	0.0%
35.00		-0.25	-0.25	0.0%
30.00		-0.25	-0.25	0.0%
25.00		-0.25	-0.25	0.0%
20.00		-0.25	-0.25	0.0%
15.00		-0.25	-0.25	0.0%
10.00		-0.25	-0.25	0.0%
5.00			-0.25	#VALUE!

AIR CH. Slope= 0.000000	**AIR CH. Intercept =** -12.190000	**AIR CH. Corr. =** #DIV/0!
GAS CH.Slope= 0.000000	**GAS CH. Intercept=** -0.253320	**GAS CH. Corr.=** #DIV/0!

Comments:

FORM 4-3
MASS FLOW METER CALIBRATION FORM
Using Bios Dry-Cal Flow Standard(s)

CALIBRATOR APPLICATION INFORMATION:		NETWORK:		SITE:	
Calibrator Model/S/N:		Date:			
Calibration Site:		Calibrated by:			
Barometric Pressure (Pa, in mmHg):		Air Temp. (Ta, in deg. C):		(=deg. K):	273
Flow Standard Model:	BIOS DC-2M	Flow Cell Model No:			
Flow Standard Base S/N:		Flow Cell S/N:			
Base Certification Date:		Flow Cell Certification Date:			

Check One: ____________ Air Channel ____________ Gas Channel

(X) Mass Flowmeter Display Set Point	Flow Meter Readings (5 sets of 10 averaged flows) F_1 (sccm)	F_2 (sccm)	F_3 (sccm)	F_4 (sccm)	F_5 (sccm)	(Y) Average Flow (sccm) $(F_1+F_2+F_3+F_4+F_5)/5$	(Y') Indicated Flow From Curve (sccm)	Δ % (Y - Y') x 100 / Y'	Mass Flowmeter Voltage Output
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	
						0.00	#DIV/0!	#DIV/0!	

Slope = **#DIV/0!** **Intercept =** **#DIV/0!** **Corr. =** **#DIV/0!**

Comments:____

____

____

Technician ____
(signature)

FORM 4-4

REFERENCE SHEET FOR DILUTION CALIBRATOR FLOW RATES AND SETTINGS

(Based on site location of gas cylinder and dilution calibrator referenced below)

Network:	PAMS	Site(s):	Mark Twain School

Calibrator Model No:	TAPI T-700	Calibrator S/N#::	69
O3 Transfer Standard Cert Date:	Not Applicable	Flow Meters Calibration Date:	9/22/11 (1st Placed in Service)
O3 Re-Cert Due Date:	Not Applicable	Flow Meters Re-Cal Due Date:	3/22/2012

GAS STANDARDS:

Vendor	Cylinder No.	Gas Type	Certified Conc. (PPM	Cert Date	Due Date
Scott Marrin	MM11574	CO	5,040	8/18/2011	8/18/2013
Scott Marrin	MM11574	SO2	50.6	8/18/2011	8/18/2013
Scott Marrin	JJ9012	H2S	48.7	8/18/2011	8/18/2012

Instructions for using this form:

1.) Using either the orange or blue cells in the "MFC Cal Data" boxes below, enter the most recent valid cal curves for the Air & Gas calibrator DISPLAY settings, and the blue cells are to be used ONLY if the MFC cal curves are referenced to the MFC output voltages.

2.) Again, using either the orange or blue cells in the "Air MFC Set Pt" box below, enter appropriate set points for the Air MFC (this will to the calibrator's Display (i.e., in the Orange cells), then enter the "Air MFC Set Pt." settings in the Orange cells as well. The

Enter the desired test gas concentration in ONE yellow cell ONLY for each row (either for CO, SO2 or NO).
The form will calculate

MFC Cal Data (Referenced to Calibrator DISPLAY)	
Air MFC Slope:	1.000000
Air MFC Intercept:	0.000000
Gas MFC Slope:	1.000000
Gas MFC Intercept:	0.000000

MFC Cal Data (Referenced to MFC Voltage Out)	
Air MFC Slope:	
Air MFC Intercept:	
Gas MFC Slope:	
Gas MFC Intercept:	

EFFECTIVE DATE OF USE IN NETWORK:

ENTER DESIRED Concentration			ACTUAL GAS Concentration			CALIBRATOR SET POINTS & FLOW RATES					
CO	SO2	H2S	CO	SO2	H2S	Gas MFC Set Pt.		Gas	Air MFC Set Pt.		Air MFC
(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	Display	Vout	MFC	Display	Vout	Flow Rate
	0.400		39.8	0.400		0.0398	#DIV/0!	39.8	5,000		5,000
	0.100		10.0	0.100		0.0099	#DIV/0!	9.9	5,000		5,000
		0.400			0.400	0.0414	#DIV/0!	41.4	5,000		5,000
		0.100			0.100	0.0103	#DIV/0!	10.3	5,000		5,000
	0.000	0.000	0.0	0.000	0.000	OFF	OFF	OFF	5,000		5,000

FORM 5-1: SO2 ANALYZER CALIBRATION FORM

Calibration Data on This Form Are For:___________ P/Z/S Check__________ Unadjusted Cal.______________ Adjusted Cal.

Network:	Site:	Date:
Time Off-Line:	Time On-Line:	Technician:

Calibration Equipment Info.	Analyzer Mfg./Model No.: TAPI T100	S/N:	Last Cal'd:
	Calibrator Mfg./Model No.: TAPI T700	S/N:	Cal. Date:
	Gas Cylinder Supplier: Scott Marrin Gas	Cyl. Cert. Date:	Cyl. Pressure: PSIG
	Gas Cylinder ID #:	SO2 Cyl Conc.: ppm	Site Temp.: ^{o}C

Analyzer Calibration Settings	**"As Found" (Before Any Adjustment)**	**"As Left" (After Adjustment)**
SLOPE		
OFFSET		

INPUT GAS DATA					**OBSERVED RESPONSES**	
Gas Ch. Display Setting	Gas Ch. Flow Rate (LPM)	Air Ch. Display setting	Air Ch. Flow Rate (LPM)	SO2 Gas Input Conc. (PPB)	SO2 Channel Response (PPB)	Δ%
OFF	OFF			0		

LINEAR REGRESSION ANALYSIS RESULTS

Slope=	Intercept=	Corr. (r)=

NOTES:

1. A valid "As Found" P/Z/S check must be performed prior to performing an adjusted-response calibration IF the analyzer is operational and producing data.

2. If the results of the "As Found" P/Z/S check cited above exceed ±10 ppb for zero and/or ±10% deviation for either span or precision response, the technician should perform an "As Left" (Adjusted Response) calibration.

3. Any "As Left" (Adjusted Response) Calibration results should be ≤ ±5 ppb for zero and ≤ ±5% of True for any non-zero point.

Comments: ____

____

Technician:____________________________

QA Review:____________________________

FORM 7-1: SO2 SYSTEM ROUTINE CHECK FORM

Network: ______________________________ Site Name:______________________________

Dates of Checks:➔				
Operator's Initials:➔				

GENERAL SITE CONDITIONS

Shelter Min/Max Temp. (Must be within 20º-30º C)	Min	Max	Min	Max	Min	Max	Min	Max
Shelter and Site Conditions OK? (Y or N; Explain in "Comments" if N)								
Sample intake and lines clean, intact and free of moisture? (Y or N)								

SO_2 ANALYZER CHECKS

Analyzer Mfg./Model#: ______________________ S/N: ______________________ Last Cal. Date: ______________

Analyzer in normal SAMPLE mode? (Y or N):									
Analyzer RANGE set to 500 PPB and SINGLE range? (Y or N):									
Analyzer STABIL value (PPB):									
Analyzer SAMP PRESS (in-Hg-A):	(Ambient ±2 in-Hg-A)								
Analyzer SAMPLE FLOW (cm^3/min):	(650 cm^3/min ± 10%)								
Analyzer PMT SIGNAL (mV) at SO_2 CONC. (PPB):		PMT	SO_2	PMT	SO_2	PMT	SO_2	PMT	SO_2
Analyzer UV LAMP (mV):	(1000 to 4800 mV)								
Analyzer LAMP RATIO (%):	(30 to 120 %)								
Analyzer DARK PMT (mV):	(-50 to 200 mV)								
Analyzer DARK LAMP (mV):	(-50 to 200 mV)								
Analyzer SLOPE:	(1.0 ±0.3)								
Analyzer OFFSET (mV):	(<250 mV)								
Analyzer HVPS (V):	(~400 to 900 V)								
Analyzer RCELL ON? (Y or N):									
Analyzer RCELL TEMP (º C):	(50º C ± 1º C)								
Analyzer BOX TEMP (º C):	(ambient temp + ~ 5º C)								
Analyzer PMT TEMP (º C):	(7º C ± 2º C constant)								
Analyzer ETEST (mV):	(2000 mV ± 1000 mV)								
Analyzer OTEST (mV):	(2000 mV ± 1000 mV)								
Analyzer REF_4096_MV (mV):	(4096mv±2mv and Must be Stable)								
Analyzer REF_GND (mV):	(0 mv±0.5mv and Must be Stable)								
Most recent SO_2 AutoCal (Level 2) SPAN (PPB):	(400 PPB ±40 PPB)								
Most recent SO_2 AutoCal (Level 2) ZERO (PPB):	(<10 PPB)								
Any analyzer ERROR MSGS? (Y or N):									
Change sample particulate filter? (Y or N)									

Comments: ____

Technician:______________________

QA Review:______________________

ENVIROPLAN CONSULTING

FORM 8-1: INSTRUMENT MAINTENANCE LOG

Mfgr:	Model:	S/N:

Date of Maintenance	Maintenance Type & Tech Initials		Maintenance Performed (Describe)	Instrument In Use At (Network and Site)
	Preventive	Corrective		